105

ROAD FROM KYOTO, PART II: KYOTO AND THE ADMINISTRATION'S FISCAL YEAR 1999 BUDGET REQUEST

HEARING

BEFORE THE

COMMITTEE ON SCIENCE
HOUSE OF REPRESENTATIVES

ONE HUNDRED FIFTH CONGRESS

SECOND SESSION

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ROAD FROM KYOTO—PART 2: KYOTO AND THE ADMINISTRATION'S FISCAL YEAR 1999 BUDGET REQUEST

THURSDAY, FEBRUARY 12, 1998

HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE,
Washington, DC.

The Committee met, pursuant to notice, at 9:58 a.m., in room 2318, Rayburn House Office Building, Hon. F. James Sensenbrenner, Jr., Chairman of the Committee, presiding.

Chairman SENSENBRENNER. The Committee will come to order.

Today we continue with our hearings on the Kyoto Protocol, the U.N. treaty that would mandate the United States to cut its greenhouse gas emissions by 7 percent below 1990 levels by 2008 to 2012. As I said in opening the hearing held by the Science Committee on February 4th, I believe this treaty to be seriously flawed—so flawed, in fact, that it cannot be salvaged. In short, the treaty is based on immature science, costs too much, leaves too many procedural questions unanswered, is grossly unfair because developing countries are not required to participate, and will do nothing to solve the speculative problem it is intended to solve.

Last week, Dr. Jay Hakes, the Administrator of the Energy Information Administration, testified that the EIA projects the Protocol would require the United States to cut carbon emissions by 550 million metric tons, or 31 percent below the levels expected in 2008 to 2012. Dr. Hakes said that, "It is unlikely the adjustments can be achieved without a significant price mechanism," and that, "Under most scenarios the price mechanism selected would slow somewhat the rate of economic growth."

In plain English, what Dr. Hakes was saying was that the only way we can meet the emissions reduction mandated in the treaty is through a significant increase in energy prices and that this will hurt the economy. Such candor is refreshing, and I hope to hear some more of it today.

There are basically three ways of increasing our energy prices—all harmful to American consumers and the American economy. One is through a carbon or BTU tax, which the Administration has correctly rejected as political poison. The second is through an international trading and joint implementation scheme—outlined in the Protocol, with details to be worked out in Buenos Aires in November—that would require the users of carbon-rich fuels to purchase credits to offset their emissions. And the third is through regulatory fiat. No matter which option is selected, the net result will be the same—the U.S. consumer will get stuck picking up the tab.

In addition to raising U.S. energy prices, the U.N. treaty imposes the burden of emissions limits solely on the United States and other developed countries, placing Americans at a competitive disadvantage against foreign competition. Higher energy costs and cumbersome regulations will encourage American industries, agriculture, and jobs to move overseas to countries like China, India, and Mexico that are under no such obligations.

Whether or not the Kyoto Protocol's fundamental flaws can be worked out in the diplomatic arena remains to be seen and will be the subject of further hearings. In the interim, we will examine the Administration's Fiscal Year 1999 budget requests that are directly related to the Kyoto process. In particular, we will consider the Administration's proposals for the U.S. Global Change Research Program and the Climate Change Technology Initiative.

The Climate Change Technology Initiative is a 5-year package of research and tax credits. It includes $2.7 billion research and technology initiative, and a $3.635 billion package of tax credits to reduce U.S. greenhouse gas emissions. The Administration has proposed a significant spending increase in Fiscal Year 1999 for the Initiative—some $473 million, or nearly 58 percent, for all agencies—with the bulk of that increase going to the Department of Energy and Environmental Protection Agency. There is also a large increase, some $50 million, or 22 percent, for the Partnership for a New Generation of Vehicles, which is coordinated by the Commerce Department's Under Secretary for Technology.

We know that advances in technology can provide us with a better, cleaner, and more prosperous world for future generations. However, we also know that advances in technology cannot and will not work to a U.N. schedule. Furthermore, we have to be sure that we do not repeat the mistakes of the 1970's by throwing large amounts of money at dubious programs that won't get results.

At this point, I have an open mind with respect to the Administration's Fiscal Year 1999 proposals. But I must say, that a cursory examination indicates that there are a number of retreads—with some reminiscent of the Carter Administration—and several appear to be, "unwarranted corporate subsidies," to use a phrase from President Clinton's October 17, 1997, statement on line item vetoes in the 1998 Energy and Water Development Act. In addition, I find it curious that the EPA is requesting a $5.4 million increase for domestic and international implementation efforts related to the Protocol, including, "securing meaningful participation from developing countries," when the treaty has neither been signed by the Administration nor submitted to and ratified by the Senate. I hope that we're not starting on the road toward a constitutional crisis here.

It seems to me that these programs should be judged on their merits regardless of their fealty to the Kyoto pact. When considering these budget proposals, therefore, I intend to adhere to the guiding principles I put forth when I took over as Chairman of this Committee. First, federal R&D must focus on essential programs that are long-term, high-risk, well-managed, and have a great potential for scientific discovery. Second, federal R&D needs to be highly relevant to and tightly focused on agency missions, with accountability and procedures for evaluating quality and results. And third, where possible, international, industry, and state science partnerships need to be fostered in a way to leverage scarce federal dollars. Funding for these programs that do not meet these standards should be eliminated or decreased to reduce budget demands and to enable new initiatives in more promising areas.

Finally, I want to remind those who believe that budget utopia has arrived, that the President's overall Fiscal Year 1999 budget increases new spending by $150 billion and that his planned increases for science are to be paid for with unrealized money from the proposed tobacco settlement—money which may not materialize. Further, it breaks the budget agreement and threatens to undermine the goal of a balanced budget and sustainable funding for all programs, including those related to climate change.

I, for one, believe the American people want us to keep the commitment we made last year to balance the budget without gimmicks, and I intend to work to that end.

And I yield to the gentleman from California, Mr. Brown.

Mr. BROWN of California. I thank you very much, Mr. Chairman, and with a little luck, we can get me out of the way and take a recess for that vote.

First, Mr. Chairman, let me express my admiration for your good judgment in scheduling these hearings and for the witnesses that we've seen on this hearing and the previous one. I think it presents a balanced view of the situation so far, and I want to commend you on that.

I would also like to state, as you already know, that we have some differences of opinion on the relative importance of global warming research. I happen to feel that it meets all of the fine criteria that you enunciated and that you use to judge research with. And I believe that it's very much in the national interest.

I—referring to my statement, briefly, and then I'll ask that the remainder of it be put in the record.

Chairman SENSENBRENNER. Without objection.

Mr. BROWN of California. The potential for man to affect the global climate has been recognized by most for the past several decades. Yet, the negotiations in Kyoto have brought the issue into clear focus for the first time. It has forced policymakers to begin the daunting task of balancing environmental, economic, and political values in a single framework and setting the stage for a new, and as yet uncertain, approach towards industrialization for the next millennium.

To a great extent, the debate thus far over global warming has been a disservice. Polarized political factions have struggled to define this narrowly as either an economic issue, or, alternatively, an environmental issue—job loss on the one hand versus environmental catastrophe on the other.

These definitions may be convenient, and even irresistible in an election year, but they are unfortunately so distorted as to be wrong. We cannot be blind to the fact that the scientific consensus is there; continued unchecked consumption of fossil fuels will very probably affect the climate in the future. Equally, we cannot pretend that taking action will be painless. There probably will be economic dislocations and even job loss in some sectors. There probably will be an impact on consumer habits and even higher costs for some commodities. It's also probable that there will be economic gains in other sectors with whole new industries being created, and there will be consumer benefits by the generation a new array of better appliances and goods. This is how economies always evolve, through the complex interplay of gains and losses.

I have to say that I am somewhat puzzled, Mr. Chairman, about your insistence that the science behind global warming is so uncertain and yet you seem to be very positive about the economic impact. Both of these are estimates, projections, and probably equally uncertain when you get down to it. No science can ever be absolutely final or absolutely correct. Neither can economic projections. We have to use a combination of the best scientific knowledge available and the best judgment that we have available. And on this matter, I expect that you and I will continue to have some differences over the future.

With that, I'll put the rest of my statement in the record. And let me just announce, but not ask for any action, the appointment of—the changes in the Ranking Democratic Members on our side. Bart Gordon will be the new Space Ranking Member; Tim Roemer will continue on Energy and Environment; Jim Barcia will be Ranking on Technology; the Honorable Eddie Bernice Johnson will be Ranking on Basic Research. And I thank you very much.

Chairman SENSENBRENNER. Without objection, the gentleman from California's complete statement will be in the record.

[The prepared statements of Mr. Brown and Ms. Johnson follow:]

STATEMENT BY
GEORGE E. BROWN, JR

ROAD FROM KYOTO: PART 2

Mr. Chairman, I look forward to this hearing today in examining the Administration's efforts to address the technical, scientific, and policy issues surrounding global warming. The potential for man to affect the global climate has been recognized by most for the past several decades. Yet, the negotiations in Kyoto have brought this issue into clear focus for the first time. It has forced policy makers to begin the daunting task of balancing environmental, economic, and political values in a single framework and setting the stage for a new--and as yet uncertain--approach towards industrialization for the next millennium.

To a great extent, the debate thus far over global warming has been a disservice. Polarized political factions have struggled to define this narrowly as either an **economic** issue, or, alternatively, an **environmental** issue—job loss on the one hand vs. environmental catastrophe on the other.

These definitions may be convenient--and even irresistible in an election year—but they are unfortunately so distorted as to be wrong. We cannot be blind to the fact that the scientific consensus is there—continued unchecked consumption of fossil fuels **will very probably** affect the climate in the future. Equally, we cannot pretend that taking action will be painless. There probably **will be** economic dislocations and even job loss in some sectors. There probably **will be** an impact on consumer habits and even higher costs for some commodities. It is also probable that there will be **economic gains** in other sectors with whole new industries being created and there will be **consumer benefits** by the generation a new array of better appliances and goods. This is how economies always evolve, through the complex interplay of gains and losses.

I regard the proposals we will hear today as a very good first start towards making the transition we will need to make. Yet it would be wrong to "sugar coat" the bitter pill before us and pretend that these proposals will **solve** the problem. We have a long way to go. Yet, all of our economic models, and our basic intuition tells us that the **key** to solving the problem is technology. The development of cost effective, energy efficient technologies, together with efforts to incentivize and promote consumer acceptance of these technologies will have long term benefits.

Those who believe that we need to **act today** mitigate global warming and those who believe **we need more information before acting** converge in one area—we need the basic tools to understand the paths we will need to take to create a more energy efficient society. This is what the Climate Change Technology Initiative seeks to accomplish. I hope that we can examine how we can make this initiative most effective, how we can measure its success and how we can make mid-course corrections in the future if it begins to falter.

In particular, I believe we all need to learn from the past failures and past successes for similar programs. Clearly the "no regrets" policy of five years ago was ultimately not sufficient to address the magnitude of the emissions problem as we now perceive it. Unfortunately, the Federal Government **does** need a more proactive role to make this work. In addition, despite the welcome call from both sides of the aisle today for a strong energy research program, we need to recall how our energy development programs have fared in Congress over the past five years.

Caught up in the intense ideological debates over **what** is and **what** is **not** corporate welfare, we have seen the budget requests for energy efficiency, solar and renewables, fusion, and nuclear research slashed dramatically every year by Congress. Spending today is 30% below the 1995 spending level in real terms. By the same token, the Administration has sought reductions in fossil fuels research every year since 1995 which, fortunately, Congress has rejected.

Clearly, there has not been a consensus on what an appropriate Federal role is in energy research. Faced with the stark reality that Kyoto has provided, I hope we can move beyond the past ideological policy debate and set a clearer goal for what we need to accomplish over the next decade.

Mr. Chairman, I look forward to the testimony today.

FULL COMMITTEE HEARING
STATEMENT
CONGRESSWOMAN EDDIE BERNICE JOHNSON (D-TX)
~~2/11/98~~
2-12-98

Eddie Bernice Johnson

Thank you Mr. Chairman for holding this hearing on the implications of the Kyoto agreement.

I am pleased that President Clinton's budget request has allocated significant monies of the $6.3 billion dollars to the Climate Change Technology Initiative and the Global Change Research Program. Both of these initiatives address the global climate problem and offer expedient solutions to the problem.

I agree with the use of these funds to be targeted towards Research and Development practices. Research and development is a necessity for the U.S. to reduce greenhouse gas emissions. The monies spent to develop more fuel-efficient automobiles and trucks, energy saving technologies for commercial building and homes, energy efficient industrial processes and renewable energy sources will prove to benefit the environment in many great ways.

Research and development should be a top priority and federal agencies need financial support to continue their research agendas. Although DOE and NSF show moderate increases of funding in the Global Change Research

Program, NASA's portion is proposed to decline by several percent. I have been reassured by the Administration that NASA has identified efficiencies and cost cutting measures that allow this decline without loss of scientific content.

The U.S. is taking actions at the federal and private levels to insure that we are addressing the global climate problem. However, I am concerned with the research and development activities of developing countries.

The global climate problem cannot be solved with only a few participants addressing this problem. I would like to urge other countries to allocate substantial funds for research and development activities as related to the deployment of energy efficiency.

Thank you.

Chairman SENSENBRENNER. And the Chair will notice at our next Full Committee meeting the approval of the changes in Ranking Members. Without objection, all members' opening statements will be placed in the record at this time. Without objection, the Committee—or the Chair—is authorized to declare recesses of the Committee during roll call. And the Committee stands recessed for 10 minutes for this roll call, and asks the members to be back promptly.

[Brief recess.]

Chairman SENSENBRENNER. The Committee will be in order.

The Chair will swear in the witnesses. Will each of you please rise. Raise your right hand please.

Do you, and each of you, solemnly swear that the testimony you are about to give before this Committee will be the truth, the whole truth, nothing but the truth so help you God.

Dr. GIBBONS. I do.

Dr. MONIZ. I do.

Mr. GARDINER. I do.

Mr. BACHULA. I do.

Chairman SENSENBRENNER. The reporter will note that all four witnesses answered in the affirmative.

Today's witnesses will be the Honorable John H. Gibbons, Director of the Office of Science and Technology Policy; the Honorable Ernest J. Moniz, Under Secretary of Energy; the Honorable David M. Gardiner, Assistant Administrator for Policy, Planning, and Evaluation of the EPA; and Gary Bachula, Acting Under Secretary for Technology at the U.S. Department of Commerce.

Without objection, all of your written statements will be inserted in the record in your testimony. The Chair would request that each of you summarize your statements in about 5 minutes or so, so that we will have plenty of time for Committee members to answer and ask questions.

The first witness will be The Honorable John Gibbons. Jack, you may proceed as you would like.

TESTIMONY OF THE HONORABLE JOHN H. GIBBONS, ASSISTANT TO THE PRESIDENT FOR SCIENCE AND TECHNOLOGY, AND DIRECTOR, OFFICE OF SCIENCE AND TECHNOLOGY POLICY, EXECUTIVE OFFICE OF THE PRESIDENT, WASHINGTON, DC

Dr. GIBBONS. Thank you, and good morning, Mr. Chairman. I want to thank you and the Committee for inviting us to testify. I will focus on the U.S. Global Change Research Program, its current program and the project, and its relationship to the Kyoto Protocol.

As you know the USGCRP began under President Bush in 1989, and it is designed to provide us with the scientific information that we need to make better decisions about climate change—to understand it and, therefore, have a firmer basis, a more thoughtful basis, for making policy decisions. So, I'd like to describe briefly what we're doing, and some things that we have learned. And I would address these issues, of course, in much more detail in my written testimony which I have provided for the record.

I also have included in that provision for the record our 1999 budget requests by agency across the 11 agencies that participate in this program and a copy of a publication from my office entitled, "Climate Change: the State of Knowledge."

Finally, Mr. Chairman, although I don't have it with me today, we will be delivering to the Committee within about 2 weeks our 1997 annual report on USGCRP called "Our Changing Planet."

I do want to stress the fact that the climate change research program is distributed across 11 agencies of government. It totals about $1.86 billion a year and it is integrated at both the program and budget level. It's a good example of where we are able to get the best of the resources of the relevant agencies and pool it together into a single integrated program.

Now, I also want to emphasize that the USGCRP planning for this year was not directly related or driven by the Kyoto negotiations. This program is shaped by the developing scientific questions and the longer-term consideration by the scientific community of the scientific information that is seen as most relevant to understanding climate change and, therefore, most relevant to the needs of U.S. policymakers.

I feel climate change is the preeminent environmental challenge that faces us as we move into the next century. This research program and its companion programs in other nations are providing us with a wealth of compelling scientific evidence of past history of climate change and also of human-induced climate change that has been occurring in recent decades. I'm not alone in the opinion that there is strong scientific evidence of human-induced climate change. The vast majority of the world's scientists who study this issue do agree. There's no question, for example, that atmospheric concentrations of carbon dioxide have risen dramatically—by about 30 percent over the last century—as a direct result of human activities. The concentration is now about 365 parts per million CO_2, and this is higher than any level seen in the measured records from ice cores that date back 160,000 years. This is clearly shown on figure 2 of my detailed written testimony for you.

Now, I know there are a lot of arguments about this business, but as Senator Moynihan once said, "We can each have our own opinions, but we cannot each have our own facts." And I'm speaking about facts in this case, about this fundamental rise of concentration of carbon dioxide.

Now, if we continue business as usual, and I sure hope we don't, we will pass through a doubling of pre-industrial CO_2 in the next half century, and by 2100, we would reach over 700 parts per million of carbon dioxide—well on the way toward treiling, or beyond, in terms of that concentration. At that kind of concentration, the atmospheric concentration would be higher than anything the earth has experienced in 50 million years. The associated rate of temperature change would exceed anything seen since the dawn of civilization 10,000 years ago.

Over this intervening 10,000 years, human settlements and ecological systems have optimized themselves in a period of remarkably constant climate, and they've optimized themselves to that particular climate. That worries me; that we may be departing radically from something that both humans and plant and animal systems have been optimizing to for 10 millennia.

The physics and chemistry underlying climate change have become much more compelling over the past few years. And they've led to the prestigious IPCC to include that, "The balance of evidence suggests a discernable human influence." That is, we're seeing the fingerprint of human activities emerging from the inherently noisy climate system.

The consequences of climate change, Mr. Chairman, will not be confined to the physical climate; the socio-economic and ecological systems are also very much at risk, with the rate of climate change perhaps as important, if not even more important, than the overall magnitude of climate change. Let me repeat that: the rate of change of these concentrations may be more important than the absolute concentration itself.

Finally, we can't, and for this reason, we can't ignore the possibility of abrupt change. We may not experience simply a slow changing climate from increased greenhouse gasses, rather, the Earth may also experience an abrupt and drastic change in climate if, for example, the North Atlantic current—or the ocean conveyer belt—were to stop abruptly, which in fact, has happened in past Earth history—long before we began to affect climate ourselves. Such a dramatic threshold, or instability—metastability or trigger—could cause massive world-wide disruption of food production.

Now, we need to continue a vigorous effort in climate change science to both help us understand what has been going on and what is happening, but also to give us a sense of how we can confront sensibly and thoughtfully the challenge in front of us.

Along these lines, I'm pleased to say that the Administration is continuing its very strong support for the climate change research program with a budget request of about $1.86 billion for Fiscal Year 1999, which is essentially a level budget projection from last year. We've made some changes inside that budget that we can speak about, but it's basically a level and sustained research budget.

The research questions we must now address have to focus increasingly, we feel, on the impacts that climate change will cause and how society can cope with such changes and advert untoward impacts. The USGCRP, then, is focusing increasingly on these emerging questions of impacts and adaptation, as well as thoughtful action that can be taken over time. We're moving from global review to increased emphasis on regional detail as our understanding improves. And we're moving from a physical and chemical approach to understanding these dynamics, to one that places increasing emphasis on biological systems. And I think that's an important move as the science develops.

We also——

Chairman SENSENBRENNER. Dr. Gibbons, could you wrap it up. You're at about 8, 9 minutes now, and we do want to have some time for the other witnesses and the members of the Committee who are here in greater number than anticipated.

Dr. GIBBONS. Mr. Chairman, I'm delighted to see the turn-out. And time goes fast when you're having fun. So, let me finish up quickly.

We are moving to our first national assessment of the consequences of climate change and we will be reporting to Congress late in 1999 in that regard. And I would say, Mr. Chairman, that we really need a significant increase in research, development, and the deployment of clean energy technologies. And I'll leave that to my colleague, Dr. Moniz, to address.

So, I think we have to remember this, Mr. Chairman, business-as-usual projections already assume steady improvements toward lower carbon intensiveness in our economy. They're already in there. We already assume a significant improvement in that efficiency year by year. But maintaining that kind of innovation is not going to be enough. We have to amplify it, or to accelerate that.

The second thing is—in my conclusions is—that the longer we have to transform our energy system to a less carbon intensive one, the easier it is going to be. That's a fundamental point that is both economic and technological. The longer—as we pace our way into this business, the longer—we have to effect this action, the less traumatic it is going to be. And, I think, if you look at the least cost path to get us to a point that is deemed an appropriate target for us, it means that we have to begin this action, not in the middle of the next century, but by about 2015. And, I think it is figure 3 of my testimony, indicates the reasons for that.

Mr. Chairman, I will stop my remarks at this point. I thank you for inviting me, and I'd be happy to take questions later.

[Dr. Gibbons' prepared statement and biography follow:]

TESTIMONY OF
JOHN H. GIBBONS
ASSISTANT TO THE PRESIDENT FOR SCIENCE AND TECHNOLOGY
BEFORE THE
COMMITTEE ON SCIENCE
UNITED STATES HOUSE OF REPRESENTATIVES

HEARING ON GLOBAL CLIMATE CHANGE
FEBRUARY 12, 1998

Introduction

Thank you for providing the opportunity to talk to you today about the U.S. Global Change Research Program's (USGCRP) current and planned activities. The best way to describe how these activities relate to the Kyoto Protocol is to describe the current state of scientific knowledge of climate change, a significant portion of which is the product of our Nation's strong support for the USGCRP since its inception.

The USGCRP began as a Presidential Initiative in 1989, and was codified by the Global Change Research Act of 1990. The program has been strongly backed by every Administration and Congress since its inception. The FY 1999 Budget Request demonstrates President Clinton's ongoing commitment to the program, with an overall request of approximately $1.86 billion dollars. The President and the Vice President believe that global change research is one of the foundations of a sustainable future. The Administration looks forward to working with the Congress to carry on this bipartisan tradition of support for sound science.

I want to emphasize that the planning of the USGCRP budget and research programs for this year, or any year, were not directly impacted by the Kyoto negotiations. The USGCRP is not a policy-driven program, but rather is driven by critical science questions and the need to develop a long term understanding of the scientific information that is of most relevance to U.S. policy makers. The results obtained through the sustained USGCRP research effort over the past decade have been very helpful in U.S. government climate change policy deliberations. As we look ahead to the next decade of global change research, it is apparent that much of the USGCRP research effort is addressing questions of ecological impacts and rates of change, both of which are relevant to the decisions the world must make about long term emissions trajectories beyond 2010.

The USGCRP, along with the global change research efforts supported by other countries such as Japan and the European nations, has provided the knowledge base for national and international decision making on climate change issues, both by providing research results directly to national governments and to the international process of the Intergovernmental Panel on Climate Change (IPCC). The IPCC draws upon the best science from around the world to produce state-of-the-art syntheses of information required by policy makers. The IPCC involves more than 2000 scientists from more than 50 countries. The IPCC process has provided compelling evidence of changes in atmospheric composition that are occurring now, the future changes we can expect if we don't take action to reduce emissions of greenhouse gases, and the implications of these changes for socio-economic and ecological systems.

Over the past decade, a series of global environmental changes have been documented in increasing detail. We have demonstrated that climate change, the loss of biodiversity, stratospheric ozone depletion, alteration of the land surface, and changes in the nitrogen balance of the Earth's soils and waters are all occurring and changing the environment on a global-scale. We have also established beyond reasonable doubt that human activities are among, and in some cases are the dominant, driving forces of such change. We recognize that these changes are interrelated, and that they form a suite of multiple stresses affecting people and the Earth's ecosystems.

The USGCRP addresses the broad suite of global change issues. The USGCRP has four priority areas: short term climate variability -- such as El Niño; climate change over decades to centuries; changes in atmospheric chemistry; and changes in land cover and terrestrial and aquatic ecosystems. Components of these four research priorities are directly relevant to increasing our understanding of climate change and its effects. The USGCRP has also made and continues to make a very large investment in the creation of new observing and data management systems (primarily in the NASA Earth Science Program) that hold the promise of achieving a new level of understanding of the Earth system and the relationships of its components. I have included attachments that summarize the USGCRP's major achievements in FY1997 and the level of investment proposed for each participating agency for FY1999 (attachments).

As I will describe below, the scientific evidence that climate change is occurring, and that human activities are playing a significant role in causing such change, is clear and compelling. Without the USGCRP and its companion programs in other nations, we would not have the objective information we need to recognize and deal with this issue. This evidence has led the nations of the world to begin working together in the Framework Convention on Climate Change to mitigate the effects of climate disruption. The United States has led the world in addressing this global environmental issue by supporting the scientific research that continues to increase our understanding of climate change and its effects, by negotiating an agreement at the Third Conference of Parties to the Framework Convention, in Kyoto, Japan. This Convention features market mechanisms and flexibility to assure cost effective mitigation, and the development of the clean energy technologies that will benefit the economy while reducing greenhouse gas emissions. President Clinton's leadership has been instrumental to U.S. achievements in each of these areas. The President's 1999 budget request, which strongly supports climate change research and technology development and deployment, demonstrates the ongoing commitment of the Administration to confront the challenge of climate disruption.

The Science of Climate Change

We've known for about a century that a natural greenhouse effect keeps the Earth's temperature about 60 degrees F warmer than it otherwise would be. Water vapor, CO_2, and other trace gases, such as methane, nitrous oxide, and hydrofluorocarbons (HFCs), trap heat, and keep it from being re-radiated from the Earth back to space. Without this natural warming effect, life as we know it would not be possible.

The problem is that over the past century, human activities have added to the natural greenhouse effect by releasing enormous quantities of greenhouse gases into the atmosphere. These emissions have led to a steady increase in the atmospheric concentrations of such gases.

- The atmospheric concentration of carbon dioxide (CO_2) has increased by about 30 percent.
- Methane concentration has more than doubled.
- Nitrous oxide concentration has risen by 15 percent.

The burning of fossil fuels (coal, oil, and gas) for energy is the primary source of anthropogenic CO_2 emissions. Emissions of other greenhouse gases from a variety of industrial and agricultural processes effectively add about 20 percent to the U.S. CO_2 total. On a global scale, burning of fossil fuels now releases about 6 billion metric tons of carbon into the atmosphere each year. Changing land use patterns, such as agriculture and deforestation, also contributes a significant share, amounting to about another 1-2 billion metric tons per year. The rate at which atmospheric concentrations of greenhouse gases are now increasing is unprecedented.

The increased concentrations of greenhouse gases trap more heat at the Earth's surface. This means that there is more energy available to the climate system. This extra energy can do two things. It can increase the temperature of the atmosphere, which increases the atmosphere's water holding capacity. Or, where water is available, the heat energy can evaporate water, which is, in fact, where much of the extra energy goes. The result is that the water content of the atmosphere is also increased. The increased water vapor in the atmosphere, in general, not only enhances the greenhouse effect but also produces enhanced amounts and rates of precipitation. In addition, because storms feed on energy and atmospheric moisture, storm duration and size is increased. On the ground, there is likely to be increased runoff and flooding. All of this is based on simple physics.

So, what does this all mean? Here is some of what we know:

- Without changing the way we operate, the level of emissions and concentrations of greenhouse gases will continue to increase, resulting in a variety of global, regional and local effects.
- Global average temperature will rise, although there will be considerable variation in how much temperature changes in specific regions.

- The Earth's water cycle will intensify, with an overall increase in evaporation and transpiration (water loss from plants), as well as precipitation -- both rain and snow.
- More precipitation is likely to occur in "extreme" downpours, where large amounts of rain fall in a short period. Some areas will be threatened by increased flooding, while others will suffer through an increased incidence of drought, as continental interiors become warmer and drier.
- Over time, sea level will rise, due primarily to the thermal expansion of the oceans and the melting and retreating of glaciers.

It is very important for you to understand that the changes I am discussing are already taking place. The Second Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) describes a series of changes that have already been observed:

- Over the last century, the global mean (average) surface temperature increased by about 0.5 - 1° F.
- Over the same period, global mean sea level has already risen 4 to 10 inches, and further rise is inevitable.
- Mountain glaciers have retreated worldwide this century.
- The surface temperature this century is as warm or warmer than any century since at least 1400 AD.

When the IPCC report was written, 1995 was the warmest year on record, but new results from the National Oceanic and Atmospheric Administration (NOAA) show that 1995 has been surpassed by 1997, and that nine of the last eleven years are among the warmest ever recorded (Figure 1). 1997 also shows up as the warmest year in data records maintained by the United Kingdom Meteorological Office and the NASA Goddard Institute of Space Studies, meaning that the three most comprehensive and accurate long-term surface data records all indicate continued warming of our planet.

In addition, the Earth's ecosystems may already be reacting to these changes. A paper published in the April 17, 1997 issue of *Nature* presented compelling evidence for significant regional ecosystem response to warming experienced during the period 1981-1991:

- Over that 10 year period, high latitudes (between 45° and 70° North) sustained a longer growing season, and an advance of up to seven days in "greening" in spring and summer,
- These latitudes appear to be experiencing an increase of approximately 10 percent in photosynthetic activity, possibly due to the longer growing season, as well as increased CO_2 fertilization.

Rainfall data for the last century show that global precipitation has increased. Change can also be seen in United States precipitation trends. NOAA's Tom Karl has reviewed the records of total rainfall and extreme rainfall for the United States over the last century and reached some very interesting conclusions.

- If we look at the record of the last century, we see that U.S. precipitation has increased by 5-10 percent. To put this in perspective, this increase is equivalent to the annual amount of water that flows out of the Mississippi River.
- This increase has a lot of regional texture. Some states are suffering from lack of rain, but in many parts of the U.S., the increases have been several times greater than the average. In 1996 alone, six states set "all-time high" records for precipitation.
- Furthermore, since the beginning of this century, the frequency of intense precipitation events, where more than two inches of rain falls in a 24-hour period, have increased by about 20 percent. Such events lead to flooding, soil erosion, and even loss of life.

We know only too well how costly weather disasters can be. Since 1980 we have had 30 weather or climate events with price tags of at least $1 billion. Nineteen of the events have occurred in the last 5 years. Among the most costly were Hurricane Andrew in 1992 ($30 billion); the Mid-West floods of 1993 ($20 billion); 1995's hail storms and floods in Texas, Oklahoma, Louisiana, and Mississippi ($5.5 billion); the Southern plains drought of 1996 ($4 billion); and Hurricane Fran in 1996 ($5 billion). The winter storms that struck the Pacific Northwest in December 1996 and January 1997 are now estimated to have resulted in over $3 billion in costs and the estimated cost of Northern Plains floods that occurred in April and May of 1997 is about $2 billion and still rising. California is being ravaged by flooding this week from El Niño-associated storms with more to come.

We are seeing dramatic evidence of the costs associated with climate variability as the Western U.S. deals with this year's unprecedented El Niño event. I want to be clear that we can't say that El Niño is itself a consequence of climate change. We are gratified that we now have tools to predict El Niño conditions up to a year in advance, but I hasten to add that we still do not understand what causes such oscillations in the first place. However, we do have good long-term records and better instrumental records of this phenomena in modern times, and these indicate that the behavior of El Niños in the last twenty years or so has been quite anomalous. The disruption of what was a more regular El Niño cycle has been coincident with the recent pronounced warming of the Earth surface temperatures, and some scientist believe there may be a relationship, but no-one has produced any conclusive evidence. We have made great progress in explaining the effect of El Niño on the global climate, and our skill at predicting these events is improving markedly (e.g. we predicted nearly a year ago the Pacific storms we are now experiencing, and that Atlantic hurricanes would be diminished during this period. Yet even advance warning that makes it possible to undertake advance mitigation measures, the impacts are significant. Damage estimates in California are already very high, and we expect this total to grow over the next several months. El Niño provides a kind of case study of the vulnerability of our society to climate disruption, and should serve as a warning to us of the potential consequences of climate change.

The costs of such extreme events have doubled or tripled in each of the last few decades. This is partly because our urban and technologically advanced society has become extremely dependent on a massively integrated infrastructure for power, communications, transportation and fresh and wastewater treatment and distribution. This infrastructure is extremely vulnerable to extreme weather events. I want to emphasize that one can't point to any single extreme weather event today and say for sure that global warming caused it. But we can say that such events are examples of the kinds of impacts we expect to occur with greater frequency in a warmer world. There are likely to be more "storms of the century," "100-year floods," and severe droughts in the future than there were in the past.

The temperature increases, intensification of the water cycle, and sea-level rise already observed over the past century are all consistent with theoretical predictions of the consequences of an enhanced greenhouse effect. They are also consistent with the projections from simulations of global climate by general circulation models.

The IPCC "business as usual" scenario indicates that even with continued technological improvement (such as energy efficiency increases of about 1 percent per year), unless policies to control emissions of greenhouse gases are implemented, the atmospheric concentrations of these gases will be much higher by 2100. Assuming "business as usual" CO_2 concentrations will reach about 710 parts per million by volume (ppm), a level higher than any seen on this planet in the last 50 million years (Figure 2). For context, the pre-industrial level of CO_2 was about 280 ppm, and has increased to the current level of about 360 ppm. If realized, this increase is expected to result in significant future climate changes:

- Global surface temperature would increase an average of another 2-6 °F by 2100, with a best estimate of 3.5 °F. Higher Northern latitudes are projected to warm by more. Temperature change of this magnitude would be faster than any observed changes in the last 10,000 years.
- Global mean sea level would rise another 6 to 38 inches by the end of the 21st century.
- The rate of evaporation would increase as the climate warms, leading to an increase in average global precipitation as well as frequency of intense rainfall and floods in some regions. In some regions, the soil moisture will decrease, leading to increased frequency and intensity of droughts.

Most of the climate impacts have been evaluated for a world at equilibrium after greenhouse gases have reached either 550 or 700 ppm. But stabilizing at double the pre-industrial concentration of greenhouse gases, or 550 ppm, would require massive intervention. On the other hand, a continuation of "business as usual" implies a world with far higher concentrations and far greater effects. The Geophysical Fluid Dynamics Laboratory at Princeton has recently modeled the effects of doubling and quadrupling the level of greenhouse gases:

- A quadrupling of such concentrations (to about 1100 ppm) is likely to increase temperatures in North America by 15 - 20° F, as opposed to the 5-10° F expected from doubling.
- In the growing season, soil moisture deficits would approach 30 - 50 percent for quadrupling, as opposed to 10 - 30 percent for doubling.

The implications of this amount of greenhouse gases in the atmosphere are only dimly perceived, but would be grave.

Although there is scientific uncertainty about exactly how and when the Earth's climate will respond to increased concentrations of greenhouse gases in the future, observations clearly show that detectable changes are underway. Numerous efforts are underway to assess the vulnerability of ecological, social and economic systems to future changes by defining plausible future scenarios of climate change and using model simulations to evaluate sensitivities to various levels and types of change.

The Current Situation

I find the scientific evidence for climate change in the coming decades to be compelling, and the implications for the future, without intervention, potentially disastrous. I believe that we need to confront this growing challenge now. It is clear that emissions of greenhouse gases from human activities are amplifying the Earth's natural greenhouse effect, and are leading to a warming of the planet's surface. It is also clear that this warming will, in turn, lead to a series of further climate disruptions as sea-levels rise, patterns of precipitation change. atmospheric and potentially ocean currents shift, and ideal ranges for plants and animals change faster than nature can accommodate them. Climate change is a long-term challenge, and solving this problem will require a sustained, long-term effort. Thoughtful reaction to lessen the undesirable impacts of climate change can simultaneously alleviate other problems such as air pollution and growing dependence on fossil fuels.

The longer we continue "business as usual," the faster the rate of climate change, the greater the degree of warming, and the more severe the negative effects for human and ecological systems. The sooner we leave the "business as usual" path, the sooner we can slow the rate of change and avoid more negative impacts, and the more likely it is that natural systems will be able to adapt to change, and the less probable such unanticipated events as ocean current instabilities linked both to El Niño and Northern European climate.

Climate change will force shifts in the range and distribution of many individual plant and animal species, and thus will alter many of the ecosystems, including forests and wetlands, that provide the support systems for all life on Earth. The present systems, like the present human infrastructure, evolved and optimized over about 10,000 years of relatively constant climate. If CO_2 concentration rises to 700 parts per million, as I believe it almost certainly will if we do not take action, fully one third of forests worldwide are likely to experience shifts in species composition. As a small example, in the U.S., sugar maples and beech trees may move completely into Canada, with considerable economic impact. The tourism, maple syrup production, and wood production which are so important to New England's livelihood are at risk. Ideal ranges for crops will change and agricultural pests may increase. Species that cannot migrate fast or far enough may face extinction.

We spend $2 - 3 billion dollars annually to operate and maintain our parks and refuges as unique assemblages of plants and animals. Climate change threatens this substantial national investment. Coastal flooding and storm damages may increase due to rising sea levels. One third of Florida's Everglades may be inundated, and much of the Louisiana and Mississippi coastal lands may be lost. In some Western and Northeastern areas, 50 percent or more of brown trout may be lost as waters warm too much to support them. Malaria mosquitoes may be able to survive year-round in much of the U.S., and drought may become more frequent even as total rainfall and extreme precipitation events increase. Functions provided by the natural environment, such as flood control and purification of air and water, can only be provided by intact ecological systems, and when those systems are disrupted or lost we lose the enormous benefits they provide.

The potential cost of such disruption is very serious. Several recent analyses have addressed the issue of valuation of ecosystems. Refining and extending this initial work is a necessity, as was just reinforced by a report by the President's Committee of Advisors on Science and Technology, "Teaming with Life: Investing in Science to Understand and Use America's Living Capital." Initial estimates of the total value of global ecosystem services suggest they could be in the trillions of dollars annually.

For ecosystems, the rate of temperature change may be even more significant than its eventual magnitude. As the distinguished ecologist Professor Jane Lubchenco told the President earlier this year: "The slower the rate of change in climate, the less catastrophic the results. Species are more likely to be able to migrate, to grow, and evolve if the rate of change is slow." The sooner we reduce emissions, the slower the rate of climate change we can expect.

The Framework Convention on Climate Change, to which the United States is a party, seeks to stabilize atmospheric concentrations at levels that "prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to: (i) allow ecosystems to adapt naturally to climate change; (ii) ensure that food production is not threatened; and (iii) enable economic development to proceed in a sustainable manner." Greenhouse gas concentration are already beyond the range seen in the last 160,000 years, and one could argue that the rate of climate change is already outside that range as well. Even if emissions were kept at today's levels, temperatures would rise at about 2 degrees F per century because greenhouse gas concentrations would continue to rise. The historical pollen record shows that this rate is about the fastest ecosystems migrate.

Atmospheric concentrations of CO_2 have increased thirty percent since the onset of the industrial revolution. Analyses that model global economic conditions and technological change suggest that to hold atmospheric concentrations to 550 ppm of CO_2, which represents about a doubling of pre-industrial levels, reductions in the growth rate of worldwide annual emissions must begin by about 2015. That is, if we want to follow a least-cost, long-term adjustment path, it appears that the whole world must begin to "apply the brakes" within the next 2 decades, and global emissions must begin declining steeply during the second quarter of the next century (Figure 3).

The results that give us cause for concern come from numerous studies of past climate change, from observations of ecosystems changing over time, and from model simulations that project future conditions. An important aspect of interpreting such results, especially model simulations, is accounting for uncertainty, which is often done in a very selective way by climate change skeptics. Uncertainty cuts both ways: outcomes could be less dramatic than expected based on our current understanding, but could just as well be more severe. We must remember that the current generation of impact projections is focused on a limited number of variables, and that this may result in an overly benign picture of the future.

For instance, a series of projections that includes carbon dioxide increases, temperature change, and precipitation changes now indicate that while there might be no "net" effect on global agricultural productivity, significant regional dislocations are expected, with the poorest countries experiencing the greatest losses. However, these analyses do not include potential water constraints or changes in the distribution of pests. As the scientists told us at the White House Conference on Climate Change last October 6, the impacts we have not been able to include are more likely to make the net results worse rather than better.

Further, climate change may not occur gradually. Most climate model simulations to date have assumed that climate will change relatively steadily as a result of human-induced emissions of greenhouse gases. Over the past few decades, however, there have been some indications that this might not be the case -- that instead climate might change in abrupt jumps.

Past climate conditions reconstructed from ice core records in Greenland, from ocean sediment cores in the neighboring oceanic regions, and from pollen records on land areas bordering the North Atlantic have found that climates of the past have changed dramatically over very short periods of time -- namely, over a few decades or even less. We have discovered that the apparent mechanism for the climate shifts is change in the large-scale ocean circulation of the North Atlantic (which is coupled to the circulation for much of the world). The evidence shows that in the past, the Gulf Stream has basically stopped carrying heat northward, causing significant cooling in Europe and northeastern North America. The risk of such a catastrophe exists but has been little studied; similarly the potential for abrupt sea level rise from collapse of the West Antarctic ice sheet or runaway warming from dramatic heating of the polar regions and subsequent release of methane cannot be ruled out.

If we do not alter our emissions trajectory, we will pass atmospheric concentrations of double the pre-industrial level by the middle of the next century, on the way toward a tripling, or even quadrupling. We could very well take the planet to levels that have not been seen for 50 million years in a single century, a geological blink of an eye. The Administration has received letters signed by thousands of scientists in the last few months urging action on this issue --

warning that nonlinearities or unexpected events, such as the Antarctic ozone hole, are more likely when rates of change are very fast.

We have received similar letters urging action from the economic community. They point out that paced actions can reduce costs and buy insurance against climate change. It is important to point out that the challenge of climate change poses a tremendous opportunity for American industry. It is absolutely clear that more benign technologies must begin replacing existing energy and agricultural technologies and practices, the primary causes of global climate change. Technological innovation is the key to our response to the climate challenge, and technological innovation is among America's greatest strengths. Reducing emissions requires development of clean sources of power and more efficient machines, structures, and industrial processes. There will be ancillary benefits of reduced air pollution and increased energy security at the same time. The consequences of our near-term technology choices are significant and long lasting. An appliance or an automobile lasts about 15 years, residential and commercial buildings are designed to last 20-30 years or more and power plants last 30-40 years.

In developing countries, there is a $100 billion annual market in energy supply technologies alone. Setting emission targets, providing economic incentives, and investing in research will spur the process of innovation and development of cost-effective technologies needed to address this problem and benefit the economy both here and abroad. The longer we continue "business as usual," the longer we delay the development and deployment of technologies that could provide a major competitive advantage to the U.S. in the 21st century. The time to begin investment and innovation is now. Let us unleash the power of American ingenuity and entrepreneurship to solve this problem and prove once again that environmental quality and economic prosperity go hand in hand.

Shifting the Focus of the U. S. Global Change Research Program

Until recently, the U. S. Global Change Research Program (USGCRP) has focused on observing and documenting change in the Earth's physical systems and understanding why these changes are occurring. It is now appropriately shifting from a nearly exclusive focus on physical systems to a much broader effort to understand what global change means for the Earth's biological systems and for the human societies that are dependent upon them. Even with aggressive actions implemented today to reduce future climate change, some further change is inevitable in Earth's climate. The USGCRP is currently focusing on how these climatic changes will impact the various regions of the U.S., and how we can best adapt to these changes and prepare for the future. In particular, we want to accomplish two things. First, we need to move from the global to the regional level to understand what impacts are likely to result from climate change both on its own and in concert with all the other human-induced stresses we are placing on the environment, such as pollution and resource extraction. Second, we must now move to approaches that are designed to achieve an <u>integrated</u> understanding not only of the nature and extent of physical and biological effects, but of their ramifications for our social and economic systems.

In the past year, the USGCRP established several new activities to address these critical concerns. In cooperation with OSTP, the program is sponsoring a series of regional workshops, the purpose of which is to examine the vulnerabilities to climate change and variability that are unique to each area. A table of these workshops is attached. This information will then be aggregated across regions to support the first National Assessment of the Consequences of Climate Change for the U.S., as called for by the U. S. Global Change Research Act. During 1997, the leaders of our workshops, stakeholders with a broad range of interests, and members of the scientific community have worked together to develop a blueprint for a national assessment process that examines the vulnerabilities of the United States, its ecosystems, major economic system sectors, and its social infrastructure to climate variability and climate change. A National Forum on Climate Change Impacts was held on November 12-13, in Washington, D.C. to integrate results obtained so far and continue the process of defining the National Assessment. We expect the assessment activity to take place over the next two years, with a major report issued in 1999.

Regional Vulnerabilities in the U.S.

The reports from our regional workshops provide a set of compelling statements on U. S. regional vulnerabilities, and further examine possible adaptation options. In particular, the workshops have examined how we might best cope with current environmental stresses in light of future climate change.

Alaska: The state's economic dependence on natural resources makes it highly vulnerable to climate change. Global warming will be most pronounced in northern regions. Probable consequences include drying of Alaska's interior, inundation of fragile coastal delta areas, and, most seriously, melting of permafrost, which is already underway. Continuation of Alaskan warming will lead to the disappearance of most discontinuous permafrost over the next 100 years. In many places, ground level can collapse 5 yards or more, leading to significant damages to ecosystems and human infrastructure. Houses, roads, airports, military installations, pipelines, and any other facility built on ice-rich permafrost are at risk. The melting of permafrost and the warming of tundra will lead to the release of carbon and methane deposits from the formerly frozen lands, which could make them an additional source of atmospheric greenhouse gases. Ecosystem effects include destruction of trees and caribou habitat; clogging of salmon spawning streams; reduction in forested areas; expansion of lakes and wetlands; and increased rates of coastal and riverbank erosion, slope instability, landslides and erosion.

Pacific Northwest: The dependence of the Northwest on reliable water supplies provides this region's most significant vulnerability to climate change. Model projections indicate that regional consequences of warming are likely to include changing patterns of precipitation and drought, timing of runoff, and increased inundation of coastal areas due to sea level rise. Peak runoff would come earlier in the spring because of more rain and less winter snow. Late winter-early spring flows would be enhanced, increasing the chance of spring flooding. Survival of salmon egg and smolt stages will also be impacted by increased wintertime flows. There would be reduced summer and early fall flow, particularly west of the Cascades Mountain range, due to the warmer, drier summers. This will hurt western salmon migration and spawning. In the Columbia River basin, where an overall decrease in annual run-off is likely, competition among hydropower production, fisheries protection, and irrigation will probably increase. Coastal erosion, landslides and bluff failures are also major risks to ecosystems, urban centers, and coastal development. Existing wetlands will disappear faster than new ones appear, leading to loss of coastal habitat for outmigrating salmon, spawning oceanic species, and mammals and seabirds.

Great Plains: All sectors of life in the Great Plains are dependent on a very limited water supply, and water shortages there are already a problem. The further drying expected from climate change poses the region's most significant risk. Agriculture is the base of the economy, despite the constraints of the dry and variable environment. Because agricultural water needs often exceed rainfall, water for irrigation is commonly supplied from deep aquifers, which are experiencing overdrafts and dropping water tables. As climate change leads to warmer conditions and an intensified hydrological system, the soils of the area are anticipated to further dry. The simultaneous drop in aquifer levels, greater run-off from extreme downpours, and shorter duration of snow cover will exacerbate the region's water supply problems. Drier soils could be subject to increased wind erosion, which has led to "dust bowl" conditions in the past. Better soil tillage practices would simultaneously improve soil fertility, soil carbon storage capacity, and soil moisture holding capacity. Native species will face increasing levels of competition from introduced species, such as cheat grass, Japanese brome, Russian thistle, and leafy spurge, which already account for extensive economic losses. Riparian areas (wetlands and prairie potholes), which are used intensively by hunters, anglers, and bird watchers, are extremely vulnerable to warmer, drier climate.

Southeast: The Southeast is a region of abundance, with numerous wetlands, an extensive coastline, and productive agriculture, fisheries, and forestry. Urbanization and rapid population growth are already exerting significant stress on some fragile ecosystems. The Florida Everglades have been significantly altered by human encroachment, with approximately half of the ecosystem lost or severely altered by drainage for development as well as pollution from agricultural run-off. While the Southeast's long coastline makes it a recreational playground, its low elevation renders it extremely vulnerable to sea level rise and storm surges during extreme weather events, such as hurricanes, which are expected to worsen with climate change. A 1 foot rise in sea-level, the best estimate over the next century, could erode 100 to 1000 feet of Florida beaches, damaging property as well as tourist interests.

Southwest: Rapid population growth in this arid or semi-arid region make the Southwest extremely vulnerable to water supply problems that are likely to worsen under climate change. The region is naturally subject to large climate fluctuations, which have produced fairly robust adaptation mechanisms in ranching and agriculture. The native flora and fauna are also well adapted to life in this harsh and dry environment. Surface water supplies are insufficient; forcing reliance on groundwater, use of which already exceeds recharge and is leading to subsidence in many areas. Climate change will pose serious challenges and is likely to result in significant impacts to the region's traditional economic sectors as well as tourism, development, and retail sectors that now make up much of the region's economy. Expected conditions include more extremely hot days, fewer cool days, and decreased winter precipitation. Alteration of the region's hydrologic cycle would affect quantity and quality of the water supply, with major implications for continued development in the region. Significant changes in vegetation are also predicted, with Gambel oak, Piñon pine, and Douglas fir largely disappearing from the region. Saguaro would die off in its current range, but might find a new home further east and at higher elevations.

New England: New England's economy is diverse, and many aspects are indirectly dependent on climate. Its natural areas are prized, and its fall foliage draws visitors from all over the world. The region is vulnerable to drought and severe storms, which modify its vegetation and impact production of forest and fisheries products. Warmer, drier climate could reduce ski tourism and shift optimal climatic conditions north into Canada for the tree species prized for their fall foliage and maple syrup. Coastal areas are likely to be affected by intensifying storms, sea level rise, and reduced freshwater input to estuaries. Air quality, already poor in the region's major urban areas, could decline even further as hot, humid weather increases, leading to increased incidences of respiratory illness.

Sectoral Vulnerabilities and Impacts

The USGCRP is also developing an extensive body of research that suggests that human health and ecological systems are vulnerable to climate change. The human-induced climate changes that are expected will add important new stresses on ecological and socioeconomic systems that are already affected by pollution and increasing resource extraction. The degree of vulnerability, and the amount and rate of change that is experienced in addition to existing stresses will determine the magnitude of climate change impacts.

Health Effects: According to the World Health Organization, the vulnerability of human populations to climate change varies across populations depending on environmental circumstances, social resources, and preexisting health status. In general, developing countries are more vulnerable to climate change than developed countries because of their limited capital and their greater dependence on natural resources. Climate change increases the risk of heat-related mortality and the potential for the spread of vector-borne diseases, such as malaria, dengue and yellow fever, and encephalitis, and non-vector borne diseases such as cholera and salmonellosis. The incidence of infectious diseases, which are still the world's leading cause of fatalities, may also increase.

- A study of deaths associated with summer time heat stress and winter time illnesses in 44 U.S. cities estimated that climate change could double the number of weather-related deaths. The elderly are at greatest risk in the U.S., and urban populations in developing countries are also especially vulnerable to heat stress.

- Climate change is likely to extend the geographic ranges and increase the rates of transmission of disease-carrying vectors such as mosquitoes, which can increase the populations exposed to diseases such as malaria, dengue and yellow fever. Globally, the population exposed to malaria could increase by one-third. There could be 50-80 million additional malaria cases per year, assuming no change in public health protection.
- Climate change can reduce air quality and increase levels of air borne pollen and spores, which exacerbate respiratory disease, asthma, and allergic disorders.

Water Resources: Among the most fundamental effects of climate change is an intensification of the hydrological cycle. Changes in precipitation, and increased evaporation and transpiration due to higher temperatures, can be expected to reduce water runoff, affecting the quantity and quality of water supplies for domestic and industrial uses, irrigation, hydropower generation, navigation, stream ecosystems and water based recreation. These effects will vary region by region. Increased variability in the hydrologic cycle is expected to result in more severe droughts and/or floods in some places. Impacts and mitigation expenses for such events are significant; damage estimates from the Mississippi flood of 1993 range from $10 billion to $20 billion. Areas of greatest vulnerability are those where water supplies and quality are already problems, such as arid and semi-arid regions of the world and some low lying coastal areas, deltas and small islands.

- Climate change would likely add to the stress in several U.S. river basins, such as the Great Basin, California, Missouri, Arkansas, Texas Gulf, Rio Grande, and Lower Colorado.
- The Colorado River Basin would suffer decreased summer runoff, coinciding with peak demand for irrigation, unless precipitation also increases substantially. Reductions in runoff of up to 25 percent in the basin are projected under some scenarios.
- Water scarcity in Middle Eastern and African countries also is likely to be exacerbated by climate change. Countries that are highly dependent on water originating in areas outside their borders include Syria, Sudan, Egypt and Iraq.

Forests: Climate change can dramatically alter the geographic distributions of individual tree species and of forest and vegetation types. One-third of the Earth's forests would undergo a major change in the type of vegetation that could be supported as a result of an equivalent doubling of CO_2. In northern forests, which are the forests most vulnerable to climate change, two-thirds of the currently forested area may undergo a change in vegetation type. Mountaintop species and isolated populations are particularly vulnerable. Over the next century, the ideal range for some North American forest species will shift by as much as 300 miles to the north, exceeding the ability of many species to migrate. In some instances, a change in vegetation type will result in a loss of forest area as the land converts to grassland or shrub land, while in other areas forest cover may increase.

- In the United States, western conifer forests could decrease in area and be replaced by broadleaf forests; eastern hardwood forests may be replaced by grasslands along their western boundary because of mid-continental drying. Forest damage from fire and diebacks driven by drought, insects and disease could increase.

Other Natural Areas: Natural ecosystems are highly vulnerable to degradation from climate change. Federally protected natural areas have become a repository for the Nation's rarest species and are critical for the conservation of biological diversity. The composition, geographic distribution, and productivity of many ecosystems will shift as individual species respond to changes in climate. These will likely lead to reduction in biological diversity and in the goods and services ecosystems provide for society, such as clean water and recreation. Freshwater wetlands are particularly at risk from climate change. IPCC findings show that:

- Precipitation changes and salt water intrusion from sea level rise could adversely affect the ecological communities of the Florida Everglades and degrade the habitat for many species of wading birds.
- The wetlands of the prairie pothole region of North America, which support half the waterfowl population of this continent, could diminish in area and change dramatically in character in response to climate change, significantly exacerbating the destruction already caused by agriculture. .

Coastal Areas: Even if concentrations of greenhouse gases are stabilized in the future, sea level would continue to rise long after, perhaps for several centuries. and reach levels much higher than projected for the next 100 years. For example, after an equivalent doubling of CO_2, the IPCC expects sea level to rise by 6 - 38 inches over the next century, with a "best estimate" of 20 inches, but the equilibrium sea level rise several centuries in the future is estimated to be at least 6 feet. Rising sea level erodes beaches and coastal wetlands, causes the gradual inundation of low lying areas, leading to human habitat loss and increasing the vulnerability of coastal areas to flooding from storm surges and intense rainfall. The IPCC estimates that 20 inches of sea level rise would double the population at risk from storm surges, from roughly 45 million at present to over 90 million world-wide. A three foot rise would triple the number of people exposed. Increases in coastal area populations are likely to further increase the number of people at risk.

- Along U.S. coasts, a 20 inch rise could inundate more than 5000 square miles of dry land and an additional 4000 square miles of wetlands if not protective measures are taken. A three foot rise would have greater impact, inundating much of the Southern tip of Florida among other areas.
- Internationally, low-lying areas, such as parts of the Maldives and Bangladesh, would be completely inundated by a three foot sea level rise, creating large numbers of environmental refugees, which put stress on governments and social structures. 72 million people in China would be affected, assuming existing levels of coastal development.

Agriculture and Food Supply: Agriculture is highly dependent on a number of variables that are likely to be affected by climate change, including weather patterns, longer term patterns of climate variability, and, most importantly, water availability. Climate change is likely to lead to increased crop yields in many areas, but decreased yields in others, even for the same crop. The magnitude of these changes can exceed +/- 30 or 40 percent for some crops and locations. Despite these potentially large changes in yields, average global food production is not expected to change substantially. This is because farming practices are considered to be highly adaptable to different climates, because production of important food crops can shift to new locations in response to changes in climate, and because CO_2 has beneficial effects for plant photosynthesis and water use efficiency that can offset some deleterious effects of changes in climate. Impacts are likely to vary considerably across regions and some regions may suffer substantial reductions in agricultural production. In general, developing countries are more vulnerable to losses than are developed countries.

- Large reductions in soil moisture could significantly reduce flexibility in crop distribution and increase demands on water resources infrastructure.
- Increases in the range of pest habitat could increase vulnerabilities to pests and demand for, and use of, pesticides.
- In the United States, large areas of the eastern and central regions of the country face moderate to severe drying. Drought could become more frequent, particularly in the Great Plains.

Conclusion

The USGCRP and its companion programs have provided us with a substantial level of understanding of climate change and a substantial body of evidence of the seriousness of this problem and its effects.

The rates of change already imposed on the climate system are faster than any experienced over the last 10,000 years, the time period during which human civilization has developed and modern ecosystems have evolved. Current emissions trajectories, if not altered, could take us before the end of the next century -- a moment in history -- to an atmospheric concentration of CO_2 not seen on this planet during the last 50 million years. We cannot preclude some major positive feedback effects -- the collapse of the West Antarctic ice sheet which would cause a 15 foot sea-level rise; the stopping of the ocean conveyor belt which would significantly lower European average temperatures, or the runaway melting in the Arctic which holds frozen several orders of magnitude more carbon than is in the atmosphere today.

While much work remains to be done to improve the precision of impact estimates, the increasingly apparent risk of the rapidly changing atmosphere argues that near-term mitigation and adaptation measures are needed. The future plans of the USGCRP are to place an increasing emphasis on providing more detailed understanding of impacts and of the regional variation of change, both of which are directly relevant to crafting effective responses to global climate change. The USGCRP represents a prudent investment in the creation of the knowledge we need to assure a sustainable future.

Attachment 1

US Global Change Research Program 1997 Accomplishments

- A national assessment of the consequences of climate change for the United States was begun during 1997. Eight regional workshops and the U.S. Climate Forum, a major national workshop with over 400 participants, examined the likely consequences of climate change for U.S. regions and ecological and economic sectors.

- Development of the first global synthesis of information on land cover at a spatial resolution of 1 km (about 0.6 miles) was completed. These data are helping improve understanding of land cover, ocean productivity, and the cycling of carbon through the Earth system, and thus contributing to better predictions of climate change on national and global scales.

- There was continued improvement in the accuracy and lead times of predictions of seasonal climate fluctuations associated with the El Niño-Southern Oscillation, with several forecasting activities successfully predicted the onset of the 1997-98 El Niño event early enough to support effective flooding mitigation actions.

- A new 300-site survey of borehole temperatures on four continents produced a detailed record of the climate of the last five centuries and confirmed that the Earth is warming and that the rate of warming has been accelerating rapidly since 1900.

- Scientists from the NOAA National Climatic Data Center found that 1997 was the warmest year on record since measurements began, and that 9 of the last 11 years are among the warmest on record.

- Another NOAA analysis showed an average 5-10% increase in the overall amount of U.S. rainfall in the last 100 years. The frequency of heavy downpours, where more than 2 inches of rain falls in a day, has increased by about 20%. Such events lead to flooding, soil erosion and even loss of life.

- The Tropical Rainfall Measuring Mission (TRMM, a joint NASA-Japanese project) was successfully launched in November of 1997, and is providing rainfall observations that are improving our understanding of the global hydrological cycle and its role in climate change and variability.

- Ocean productivity images from the SeaStar satellite, launched in 1997 as part of an innovative public-private partnership, are playing a major role in understanding the behavior and consequences of the ongoing El Niño and in other global change research.

- Following the failure of the Japanese ADEOS spacecraft in mid-1997, NASA successfully changed the orbit of another satellite to allow resumption of near-global daily mapping of ozone, as well as stratospheric sulfur dioxide produced from large volcanic eruptions.

- USGCRP research continued to play a leading role in the Intergovernmental Panel on Climate Change (IPCC) during 1997, and was an important contribution to the IPCC special report entitled The Regional Impacts of Climate Change: An Assessment of Vulnerability and to several IPCC technical papers on other key issues.

- U.S. citizen Robert T. Watson was elected overall Chair of the IPCC, replacing Bert Bolin of Sweden, and James McCarthy of Harvard University was elected Co-Chair of IPCC Working Group II, which will assess impacts and adaptation options.

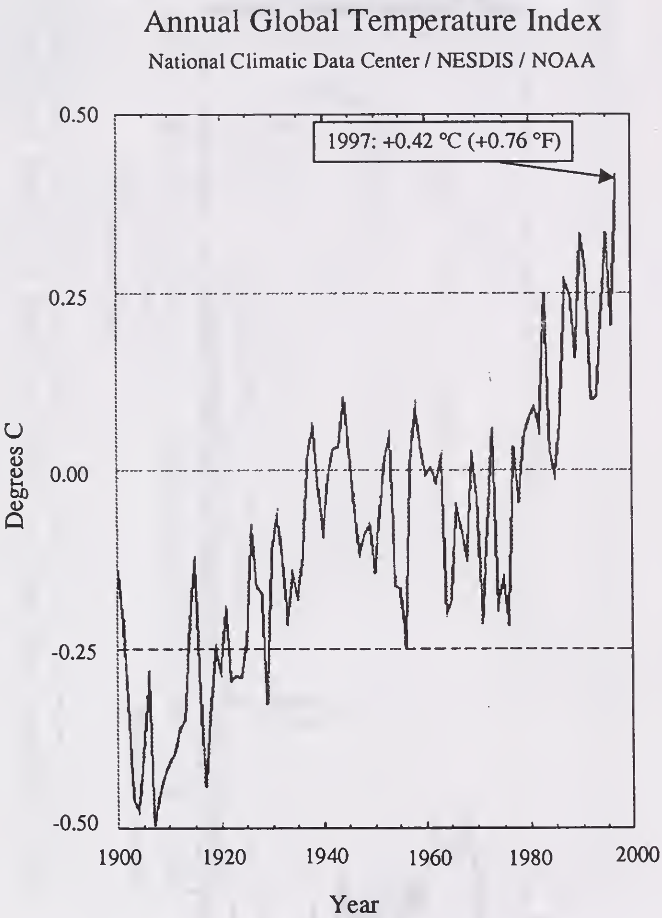
Attachment 2

National Science and Technology Council
U.S. Global Change Research Program
Budget ($millions)

	1997 Actual	1998 Estimate	1999 Proposed	Dollar Change 1998-1999	Percent Change 1998-1999
Health and Human Services	4	4	5	+1	+25%
National Aeronautics and Space Administration	1,369	1,417	1,372	-45	-3%
Energy	109	108	113	+5	+5%
National Science Foundation	166	167	187	+20	+12%
Agriculture	57	58	59	+1	+2%
Commerce	62	62	71	+9	+15%
Interior	29	29	29	--	--
Environmental Protection Agency	14	15	21	+6	+40%
Smithsonian	7	7	7	--	--
Tennessee Valley Authority	1	--	--	--	--
total	1,818	1,867	1,864	-3	-*%

*less than 1%

Figure 1



The global average temperature of 62.45 degrees Fahrenheit for 1997 was the warmest on record, surpassing the previous record set in 1995 by 0.15 degrees Fahrenheit. The chart reflects variations from the 30-year average (1961-1990) of the combined land and sea surface temperatures.

Figure 2

Atmospheric Carbon Dioxide Concentration and Temperature Change

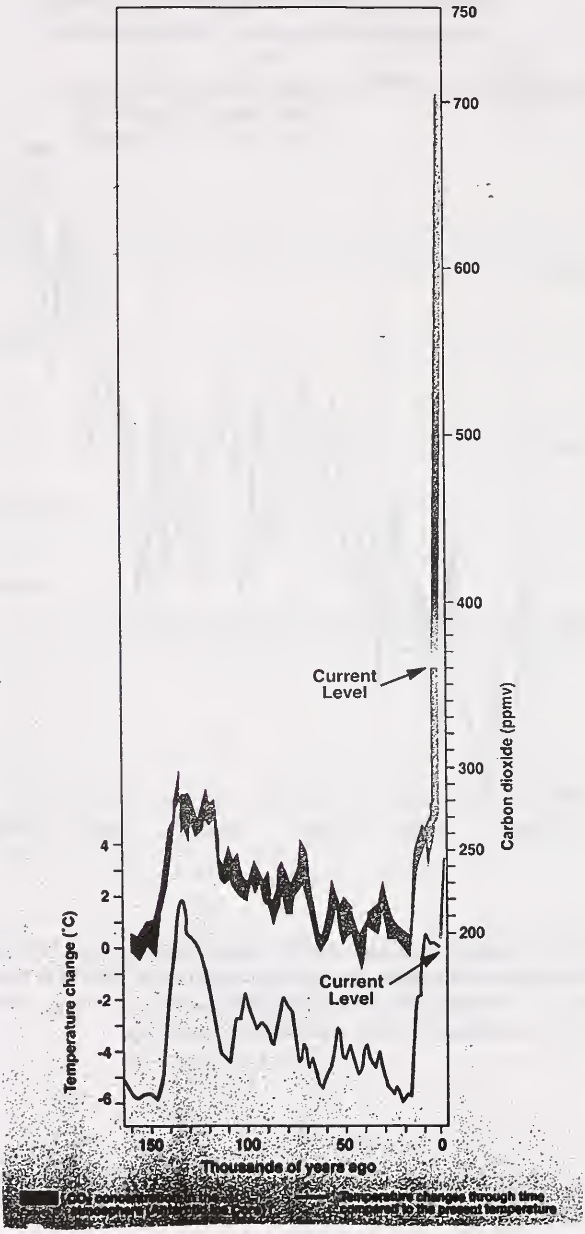
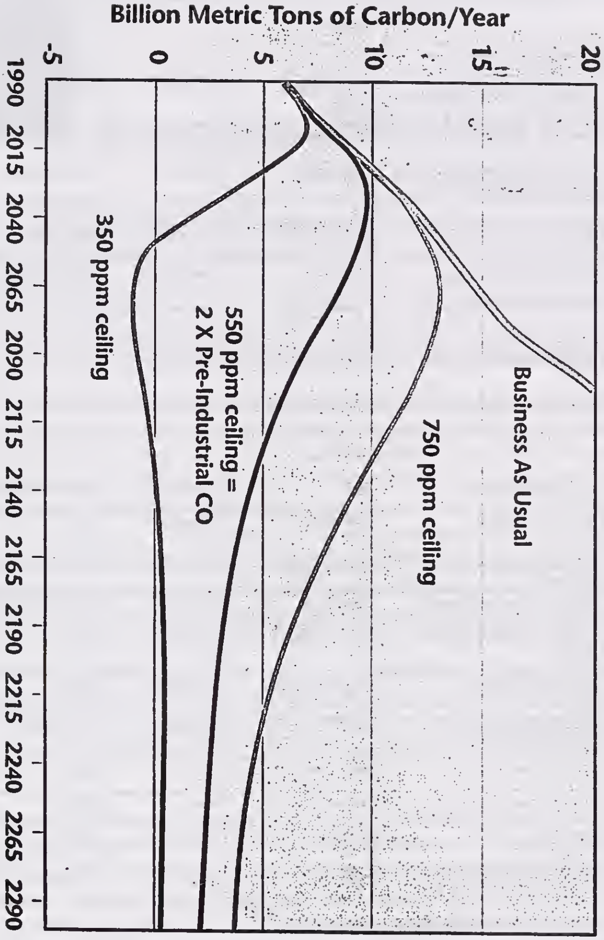


Figure 3

Atmospheric Stabilization Emissions Paths



Attachment 3

OSTP/USGCRP Regional Climate Change Workshops

Regional workshops being convened as part of the start-up phase of the National Assessment

1997 Workshops

Region	Organizing Institution(s)	Site	Dates	Coordinating Agency(s)
Central Great Plains	Colorado State University and University of Nebraska/NIGEC	Fort Collins, CO	May 27-29	DOE
Alaska	University of Alaska	Fairbanks, AK	June 3-6	DOI
Southeast	University of Alabama, Huntsville, and Florida State University	Nashville, TN	June 25-27	NASA, NOAA
Pacific Northwest	University of Washington	Seattle, WA	July 14-16	NOAA, NASA
Southwest	University of Arizona	Tucson, AZ	September 3-5	DOI, NOAA
New England	University of New Hampshire	Durham, NH	September 3-5	NSF
Middle -Atlantic	Pennsylvania State University	State College, PA	September 9-11	EPA
Northern Great Plains	University of North Dakota	Grand Forks, ND	November 5-7	NASA

1998 Workshops

Region	Organizing Institution(s)	Site	Tentative Dates	Coordinating Agency(s)
Rocky Mountains and Great Basin	Utah State University	Salt Lake City, UT	February 16-18	DOI
Gulf Coast	Southern University and A&M College	Baton Rouge, LA	February 25-27	EPA
Hawaii and Pacific Islands	CARE; University of Hawaii	Honolulu, HI	March 3-6	FEMA, NOAA, DOI
California	University of California, Santa Barbara	Santa Barbara, CA	March 9-11	NSF
Metropolitan East Coast	Columbia University	New York City, NY	March 23-24	NSF
Southern Great Plains (Parts I and II)	University of Texas - El Paso and Texas A&M University	El Paso, Texas and TBD	March 2-4 and late March	USDA, NASA
Appalachians	West Virginia University	Morgantown, WV	May 26-29	USFS
Upper Great Lakes	University of Michigan	Ann Arbor, MI	May	EPA
Caribbean/Southern Atlantic Coast	TBD	TBD	Spring	NOAA
Eastern Midwest	Indiana University	TBD	Spring	USDA

For Additional Information, Contact:

***Environment Division, Office of Science and Technology Policy**
Fax: 202-456-6025, or

***US Global Change Research Program Coordination Office**
Fax: 202-358-4103
regional.workshops@usgcrp.gov
http://www.usgcrp.gov

Biography of Dr. John H. Gibbons

John H. (Jack) Gibbons is the Assistant to the President for Science and Technology and Director of the White House Office of Science and Technology Policy. In these capacities, Dr. Gibbons is charged with providing access to authoritative information and expert scientific, engineering and technological advice for the President, Federal Officials and Congress, and with coordinating science and technology policy throughout the Federal Government. Dr. Gibbons co-chairs the President's Committee of Advisors on Science and Technology (PCAST) and manages the National Science and Technology Council (NSTC) .

He is an internationally recognized scientist and an expert in energy and environmental issues who has a deep interest and concern about the support of science and the impacts of technology on society. Following his formal training in physics, he spent the next 15 years at Oak Ridge National Laboratory. At Oak Ridge, Gibbons studied the structure of atomic nuclei, with emphasis on the role of neutron capture in the nucleosynthesis of heavy elements in stars. In the late 60's, at the urging of Alvin M. Weinberg, he pioneered studies on how to use technology to conserve energy and minimize the environmental impacts of energy production and consumption. In 1973, at the start of the nation's first major energy crisis, Gibbons was appointed the first director of the Federal Office of Energy Conservation. Two years later he returned to Tennessee to direct the University of Tennessee Energy, Environment and Resources Center. In 1979, he returned to Washington to direct the Congressional Office of Technology Assessment which provides Congress with nonpartisan, comprehensive analyses on a broad spectrum of issues involving technology and public policy where his tenure lasted over 2 six-year terms prior to his Presidential appointment on February 2, 1993.

Dr. Gibbons is a Fellow of the American Physical Society and the American Association for the Advancement of Science and was recently elected to membership in the National Academy of Engineering. He is a member of the Council on Foreign Relations. Other honors include the Federation of American Scientists Public Service Award; the AAAS Philip Hauge Abelson Prize for sustained exceptional contributions to advancing science; the Leo Szilard Award for Physics in the Public Interest from the American Physical Society; and medals from the German and French governments for fostering scientific cooperation.

Dr. Gibbons was born in Harrisonburg, VA, in 1929. He received a bachelor's degree in mathematics and chemistry from Randolph-Macon College in 1949 and a doctorate in physics from Duke University in 1954. His publications are numerous in the areas of energy and environmental policy, energy supply and demand, conservation, technology and policy, resource management and environmental problems, nuclear physics, and origins of solar system elements.

Speeches and Testimony

- "Remarks at the Dael Wolfle Lecture, University of Washington, Seattle, WA" delivered October 9, 1996
- "Remarks at The Presidential Award for Excellence in Science, Math, and Engineering Mentoring Awards Ceremony, Room 450, Old Executive Office Building, Washington, DC" delivered September 25, 1996
- "Remarks at 12th Annual EPSCoR National Conference, Renaissance Hotel, Washington, DC" delivered September 16, 1996
- "Sound Science, Sound Policy: The Ozone Story" delivered September 19th, 1995
- AAAS Forum -- "The First Rule of Tinkering" delivered June 26th, 1995
- "Remarks at AAAS Policy Colloquium" delivered April 12th, 1995
- "Remarks at the Wernher von Braun Lecture, Smithsonian, The New Frontier: Space Science and Technology in the Next Millennium" delivered March 22nd, 1995
- "Risk Assessment and Cost-Benefit Analysis for New Regulation" delivered February 6th, 1995
- "Statement on FY96 Research and Development Budget" delivered February 6th, 1995
- "Science in the National Interest" testimony delivered January 6, 1995
- "Statement on National Space Transportation Policy" testimony delivered on September 20, 1994
- "Technology for a Sustainable Future" delivered at the 1994 H. John Heinz Public Policy Symposium on September 20, 1994
- "Science in the National Interest" testimony delivered August 4, 1994
- "Plutonium and International Security" testimony delivered May 26, 1994
- "Plutonium and National Security" speech to the Public Forum on Plutonium on May 4, 1994
- "Global Agreement on Tariffs and Trade (GATT) and Research & Development

Chairman SENSENBRENNER. The next witness is the Honorable Ernest Moniz, Under Secretary of Energy. Dr. Moniz.

TESTIMONY OF THE HONORABLE ERNEST MONIZ, UNDER SECRETARY OF ENERGY, U.S. DEPARTMENT OF ENERGY, WASHINGTON, DC

Dr. MONIZ. Mr. Chairman, and members of the Committee, thank you for the opportunity to come before you today and discuss climate change and DOE's energy R&D programs. I would just note that I joined DOE 3 months ago, I might add, after serving for a year and a half under this distinguished gentleman earlier. And at DOE, the Secretary has assigned me broad responsibilities for science and technology programs across the mission areas. Accordingly, I look forward to working closely with this Committee in the years ahead.

The connection between climate change issues and energy is, of course, quite clear. And today, I want to discuss the interplay between our national energy interests, the Department's R&D programs, and environmental stewardship. The enhanced energy R&D investments provided for in DOE's Fiscal Year proposal—Fiscal Year 1999 proposal, excuse me—would indeed result in lower greenhouse gas emissions, but they also provide the United States with many other tangible energy, economic, national security, and environmental benefits.

DOE is, at it's core, a science and technology agency. And its R&D capabilities are a national resource for advancing a robust energy future, the importance of which is certainly evident to this Committee. Energy is an economic driver; energy offers economic opportunities; energy is a strategic global commodity; and energy affects the environment at local, regional, and global scales. Smog, acid rain, and particulates affect the quality of life at local and regional levels. On a global scale, there is no serious doubt that human activities associated with energy production and use have significantly altered the composition of atmospheric gases. Prudence demands a measured but strong response to ensure that sustained innovation positions America for continued prosperity and quality of life.

In that context, the Administration has recently released for comment a draft framework of a comprehensive energy strategy. The first public hearing is today in Houston. The draft strategy is organized around five common-sense, high-level goals: improve the efficiency of the energy system, ensure against energy disruptions, promote energy production and use in ways consistent with environmental quality, expand future energy choices, and cooperate internationally on energy issues. Technology is the common thread in our efforts to realize all of these goals. Our success in reaching these goals tomorrow clearly depends on our energy R&D plans today.

A broad and balanced R&D portfolio is essential. And indeed there is no one silver bullet that will solve our future energy needs. PCAST recognized this and advocated a substantial and sustained increase across the entire portfolio.

In the remainder of this testimony, I will very briefly describe—and my testimony will amplify on this—five R&D pathways which are in our portfolio. And I would note that with the exception of carbon sequestration, each of these pathways addresses multiple goals. Carbon sequestration is obviously geared uniquely towards mitigating greenhouse gas emissions. But each pathway demands a strong federal role, particularly as the R&D headlights are lowered in the private sector because of both restructuring and global competitive pressures.

One pathway is to increase our domestic energy supply. Fossil fuels will clearly continue to be the world's dominant energy source for some time. There are many examples given in my written testimony, I would just note that of a novel ceramic membrane, for example, which may make the conversion of natural gas into liquids available for transportation from remote areas much easier, therefore, allowing a shift to less carbon intensive fossil fuels.

A second approach, of course, is efficiency. U.S. energy intensity is about 50 percent higher than that of other industrialized countries, giving us lots of areas for improvement. The plain fact is that 90 percent of the energy we consume today comes from fossil and nuclear fuel. So energy efficiency is not some green alternative to the real business of traditional energy investments; rather, it is grounded in better use of our dominant energy resources. And again, many examples are spelled out in my written testimony.

A third pathway is clearly clean energy for a cleaner environment. Renewables may hold the key for appreciably slowing global warming in the longer term, while offering myriad additional benefits. Examples include: increased use of natural gas and advanced turbines in the near term, to methane hydrates in the long term; life extension of existing nuclear reactors; and renewables such as advanced wind turbines, solar and photovoltaic; co-firing of coal plants with forest and agricultural biomass.

A fourth pathway, which gained substantially more emphasis in this year's budget request, is that of carbon sequestration—the removal of atmospheric carbon dioxide through natural or induced methods. Again, the dominance of fossil fuels in our energy portfolio suggests the importance of this high-risk, high-payoff research. Examples include: the capture of combustion gases, the use of micro algae to convert power plant CO_2 to biomass, and injection of CO_2 in various geological formations.

Finally, we, of course, have a strong investment in basic research proposed. This continues to provide the foundation both for new technologies and for the policy framework that will evolve as the human health, environmental, and climate impacts of energy use become increasingly well understood. Many areas of basic research underlay future capabilities. Dr. Gibbons referred already to the biological sciences. In addition, some of the important cutting-edge research tools that will have broad applications will be specifically of use in this arena as well; for example, materials research and the new neutron source being proposed, and the great expansion in our simulation capabilities over the next decade originally driven by our needs to have a secure nuclear stockpile.

All of these pathways are part of our balanced energy R&D portfolio and are, in fact, rather consistent with the PCAST recommendations.

In using the public's funds for the public good, we do have the responsibility to manage those funds effectively—a point that you made very clearly, Mr. Chairman.

Chairman SENSENBRENNER. Dr. Moniz, your 5 minutes are up. Could you wrap it up in a couple of minutes so that we can——

Dr. MONIZ. I will indeed. I will just note that in a previous hearing we did hear strong business and state support for many of the DOE partnerships. And also that we are advancing a number of internal reforms. And I would just highlight the fact that we have an aggressive road-mapping strategy going on right now which will better link our programs to missions and to budgets.

So in conclusion, Mr. Chairman, again, I believe our budget proposal represents a prudent response to the challenge of global warming and with many concomitant benefits in terms of national security, economic, and environmental consequences.

The Department's missions are clearly linked by science. Our public investment is a key catalyst for insights and advances on many fronts, and certainly, on the front of reducing environmental impacts locally, regionally, and globally. I look forward to working with this Committee to advance those key R&D programs. Thank you.

[

r. Moniz's prepared statement and biography follow:]

STATEMENT OF

DR. ERNEST MONIZ
UNDER SECRETARY OF ENERGY

BEFORE THE
COMMITTEE ON SCIENCE
U.S. HOUSE OF REPRESENTATIVES

FEBRUARY 12, 1998

INTRODUCTION

Mr. Chairman, thank you for the opportunity to testify before your Committee on climate change and the Department of Energy's (DOE) energy research and development programs. These programs serve a broad range of the nation's energy, national security and environmental interests. The connection between climate change issues and energy is clear: fossil fuels supply 84 percent of the primary energy consumed in the United States and are responsible for 98 percent of U.S. emissions of carbon dioxide. Today, I would like to discuss the interplay between our national energy interests, the Department's energy research and development (R&D) programs, our FY 1999 budget request, and environmental stewardship.

In his speech at the National Geographic Society last October, President Clinton outlined the Administration's climate change policy framework, noting that the risks justified sensible preventive steps. Several of these steps -- making R&D investments to encourage the development and deployment of energy efficient technologies, the promotion of a broad range of energy efficient products, and a comprehensive review of Federal procurement activities to ensure that the Federal government is a leader in energy efficiency -- are advanced by the Department's FY 1999 budget submission.

The enhanced energy R&D investments provided for in DOE's FY 1999 budget request will indeed result in lower greenhouse gas emissions, but they also provide the United States with many other tangible energy, economic, national security and environmental benefits. The DOE is, at its core, a science and technology agency. In the FY 1999 Administration budget proposal, 40 percent of the DOE budget, approximately $7.2 billion, is devoted to R&D. DOE's basic science programs address Americans' passion for discovery -- probing energy and matter at the most fundamental level, decoding genetic secrets, revealing the properties of novel materials. DOE's technology programs, many in partnership with the private sector, sustain the nuclear peace, help provide abundant clean energy, and promote environmental stewardship. DOE's unique national laboratories and cutting-edge major research facilities continue to define new frontiers. The success of this system over many years, and its importance to American society in the future, is highlighted by the prestigious *1997 R&D 100 Awards*, no fewer than 36 of which went to DOE supported work. Our energy R&D programs will draw upon these world class scientific and technical resources.

ENERGY AND THE NATIONAL INTEREST

Affordable and abundant supplies of energy are critical to economic, environmental and national security. Energy is key to economic performance; it offers new market opportunities for business; it is a global commodity of strategic importance; and energy impacts the environment.

Energy and the Economy

United States expenditures for energy now top $500 *billion* annually, accounting for over 7.5 percent of our gross domestic product (GDP). The annual electricity bill for American consumers is roughly $200 billion and the cost of energy for U.S. manufacturing industries alone stands at $100 billion per year.

The United States decreased its energy use per dollar of GDP by 30 percent between 1975 and 1986, in essence representing an annual energy savings today of over $170 billion. Despite this track record, the energy intensity of the U.S. economy is 50 percent higher than that of other industrialized nations and the potential for increased energy efficiencies in the U.S. economy remains considerable.

Energy and Global Business Opportunities

The global market for energy supply equipment is about $300 billion annually. This will grow proportionately as world energy capacity doubles over the next few decades. If we include the value of products whose marketability depends upon energy performance -- such as cars or appliances -- the global market reaches into the trillions of dollars.

The United States -- with its strong scientific and technological leadership, capacity for sustained innovation and position as the preeminent economic power in the world -- needs energy policies that position us to take advantage of this large and growing global export market.

Energy is a Strategic Global Commodity

We learned through harsh experience during the two oil shocks of the 1970's, and the disruption of oil markets resulting from the Gulf War, that the price and availability of energy resources in one region can have global implications. The Persian Gulf -- one of the most politically volatile regions in the world -- currently supplies about one half of the world's exports of oil and this figure is expected to go even higher over the next 15 years.

The world will likely double its energy use by 2030 and quadruple its use by the end of the next century. Oil demand is projected to grow by about two percent annually over the next 20 years. Total world energy consumption is projected to reach 560 quadrillion Btu in 2015, an increase of 200 quadrillion Btu over 1995 totals. Competition with, and within, the developing world for scarce fossil fuel resources will become intense over the next several decades. It is essential that we continue to diversify our energy supply, both in the energy options we choose and the regions of the world from which we import oil.

Energy and Environmental Security

Energy production and use are principal contributors to local, regional and global environmental problems. Smog, acid rain and particulates affect quality of life at local and regional levels. Over the past two decades, U.S. emissions of SO_x, NO_x and CO_2 were lower than they otherwise would have been, due in no small part to technological innovations such as: more energy-efficient automobiles, scrubbers on power plants, more energy efficient buildings and home appliances, and a slow but steady infiltration of the market by alternative fuels. Much more remains to be done, and *can* be done, with concomitant health and quality of life improvements for tens of millions of Americans.

On a global scale, there is no serious doubt that human activities associated with energy production and use, primarily of fossil fuels, have over the last few decades significantly altered the composition of atmospheric gases. World carbon emissions are expected to increase by 3.5 billion metric tons over current levels by 2015, if world energy consumption reaches levels projected by DOE's Energy Information Administration. Although a detailed understanding of regional impacts awaits further research, scientific analysis overwhelmingly suggests the possibility of major societal dislocations. Prudence demands a measured but strong response in ensuring that sustained technological innovation positions us for continued prosperity and quality of life.

A Comprehensive National Energy Strategy

The Administration recently released for comment a draft framework for a comprehensive energy strategy, and we look forward to discussion with the Committee, the Congress, and the public in the weeks ahead. It is organized around several common sense, high level goals:

- *Improve the efficiency of the energy system* -- make more productive use of energy resources in order to enhance overall economic performance while protecting the environment and advancing national security;
- *Ensure against energy disruptions* -- protect our economy from external threats of interrupted supplies of infrastructure failure;
- *Promote energy production and use in ways that reflect human health and environmental values* -- improve our health and local, regional and global environmental quality;
- *Expand future energy choices* -- pursue continued progress in our science and technology to provide future generations with a robust portfolio of clean and inexpensive energy sources; and
- *Cooperate internationally on energy issues* -- develop the means to identify, manage, and resolve global economic, security and environmental concerns.

Technology is the common thread in our efforts to realize all of these goals that support our economic, national and environmental security. Our success in reaching these goals *tomorrow* depends on our energy R&D investments *today*.

SCIENCE, TECHNOLOGY AND ENERGY

There is no one "silver bullet" that will solve our future energy needs. A broad and balanced R&D portfolio is essential. Fossil fuels will continue to be the world's dominant energy source for a considerable time under any plausible scenario. Thus, improved efficiency, increased use of natural gas, reduced environmental impact in fossil resource recovery, pollution abatement, and sequestration of carbon following combustion are all important goals to be advanced by new technology.

Renewable energy technologies, with electricity delivered at costs roughly comparable with fossil sources, may hold the key for appreciably slowing global warming in the longer term, while offering myriad additional benefits. Technology options for safe, proliferation-resistant, waste-minimizing, economic nuclear power need to be preserved.

Basic research continues to provide the foundation both for new technologies and for the policy framework that will evolve as the human health, environmental and climate impacts of energy use become increasingly well understood.

Indeed, The President's Committee of Advisors on Science and Technology (PCAST), in their November 1997 report *Federal Energy Research and Development for the Challenge of the Twenty-First Century*, advocated a substantial and sustained increase across the entire energy R&D portfolio. In the remainder of this testimony, I will discuss five R&D pathways in the DOE research portfolio that will address our economic, national security and environmental goals, including the climate change issue.

1. Increasing our Domestic Energy Supply

We have or are developing technology pathways to increase our access to domestic fossil energy resources while minimizing impacts on the environment. The Department's current oil and gas program is projected to stimulate about 1,000,000 barrels per day of additional liquids production by 2010, about 20 percent short of a production goal that would stabilize domestic production after 2005. Thus, we must continue to look for opportunities to partner with our domestic oil and gas producers to: (a) improve the accuracy of reservoir imaging and diagnostics; (b) expand the use of enhanced oil recovery processes, such as CO_2 flooding, to basins beyond those that have been the traditional targets; and (c) reduce the cost of effective environmental protection in such areas as the minimization of produced water and the development of more effective air emission control technologies.

Last month, I saw firsthand the power and potential of technology during a visit to the

Alaska North Slope where a significant percentage of our domestic oil and gas is produced. While the Prudhoe Bay development impacted two percent of the surface area, the new Alpine field will impact only *two tenths of one percent* of the surface because of new drilling technologies. The North Slope also has huge reserves of natural gas, very remote from an adequate market. Last year, DOE initiated a cost-shared, joint government-industry collaboration to produce a revolutionary ceramic membrane that might significantly lower the cost of chemically converting natural gas into a middle distillate liquid. Such a breakthrough in the current limitations that transportation places on natural gas could add a billion barrels or more of vital liquids to our energy supply. The increased availability of natural gas could help reduce greenhouse gas emissions by substituting for more carbon-intensive fossil fuels.

It is worth noting in this connection that one of the *1997 R&D 100 Awards* the Department received was for the development of an energy supply technology through a laboratory-industrial partnership -- 3D seismic oil exploration software using supercomputers. For the first time, operators are performing relatively fine scale modeling of very large oil fields in their entirety, thereby increasing domestic energy resources, such as North Slope oil. The underlying computational and simulation tools were actually developed for nuclear stockpile stewardship. This is just one example of how the core competencies in the DOE labs and programs often bear fruit across multiple missions. And, as our nuclear stockpile mission drives American computational capability to 100 trillion operations per second in the next decade, dramatically enhanced simulation capability will enhance numerous energy and environmental R&D programs as well, including much higher resolution studies of global systems with concomitant improvement in regional climate predictive power.

2. Efficient Use of Dominant Energy Options

Energy efficiency is not some "green" alternative to the "real business" of traditional energy investments; rather, it is grounded in better use of our dominant energy resources, in particular fossil fuels. Advances in energy efficiency technologies could deliver substantial near-term carbon reducing impacts over the next decade by decreasing the "energy intensity" (energy consumption per dollar of GDP) of the U.S. economy. The investments we make in energy efficiency do not simply save energy -- they represent one of the cheapest, least intrusive ways of accomplishing all of our environmental objectives as well as contributing to the productivity and competitiveness of our economy and to energy security. Consequently, energy efficiency is a key thrust in our FY 1999 energy R&D budget.

Buildings. One-third of energy and two-thirds of electricity in the U.S. is consumed in buildings. Current and new technologies have a large potential to reduce energy use, cut emissions and save money for consumers and businesses. In the buildings sector, DOE is developing, in close collaboration with industry, efficient equipment, materials, and whole building designs that will reduce consumer and business costs while cutting greenhouse gas and other environmental emissions. The FY 1999 budget request for building technologies of $317 million will result in substantial R&D progress on a wide range of technologies including high-efficiency heat pumps, advanced lighting, fuel cells, insulation materials and intelligent control systems. In addition, DOE works with State and local groups, utilities, other agencies and industry to accelerate the deployment of energy efficient buildings technologies.

Industrial Technologies. Energy efficient technologies in industry have the potential to decrease energy use, cut waste and emissions, increase productivity and reduce costs. DOE is developing, in partnership with industry, a wide variety of technologies to meet these goals. These technologies are selected on the basis of industry-wide "visions" and technology "roadmaps" developed in close collaboration with the forest products, steel, aluminum, metal casting, glass and chemicals industries. In addition, DOE is developing key industrial technologies and materials that will have wide application -- including high efficiency industrial turbines and high-temperature materials. The Department also works with industry, States and universities to accelerate the use of key technologies including efficient motor systems. The FY 1999 budget request for industrial technologies of $167 million will result in substantial R&D progress on a wide range of industrial technologies in areas such as aluminum production, waste reduction, combustion efficiency, biomass feedstock use, glass smelting and industrial cogeneration.

Transportation Efficiencies. New transportation technologies have great potential to reduce our use of imported oil, improve urban air quality and reduce greenhouse gas emissions. The key Department transportation effort is the Partnership for a New Generation of Vehicles (PNGV) that is developing, in full partnership with industry, an auto with three times the efficiency of today's vehicles with no compromise in safety, size, performance, comfort and cost. Technologies under development that will contribute to meeting the PNGV goal include hybrid propulsion systems, fuel cells, compressed ignition diesel injection engines, regenerative braking, power electronics and lightweight materials. This effort is beginning to pay dividends, as evidenced by the recent announcements by all three automakers in January of high-efficiency concept cars they intend to produce. DOE is also developing highly efficient power plants for trucks and transportation biofuels. The FY 1999 budget request for transportation technologies of $293 million will result in substantial R&D progress not only for the PNGV auto; it also will focus increased effort on developing technologies that substantially improve the efficiency of light trucks and sport utility vehicles, the fastest growing transportation segment. It will allow for significant progress toward improving heavy truck fuel economy from 6-7 mpg now to 10 mpg.

Markets and Energy Efficiency. As we pursue the development of promising efficiency technologies, we are also interested in using the power of markets and competition to help increase energy efficiency. Electricity restructuring offers several opportunities in this regard. Generation plant operators who in the past have been able to simply "pass though" their fuel costs in regulated rates will, under competition, have a direct profit incentive to reduce fuel cost by lowering the "heat rate" of their existing generating plants. With competition, merchant plants using very efficient combined cycle gas technologies will be able to enter the market to compete with and displace high-cost inefficient generators. Significant merchant projects have been announced in New England and California, where restructuring is moving forward most rapidly. Restructuring can also help to accelerate the market penetration of existing and advanced combined heat and power technologies that squeezes more useful energy out of fuel than stand-alone electricity or heat generation. Finally, efficiency on the customer side of the meter can also be enhanced by competition as suppliers seek to increase market share and customer loyalty by offering high-value combinations of energy and efficiency services to their customers.

But the need for an increased investment in federal energy R&D is even more acute as the private sector, with electricity restructuring and global market pressures, is "lowering its R&D headlights" in terms of investments needed further down the road. Recently, for example, I participated in a Congressional hearing on the need for public investment in energy R&D, where Mr. William Keese, chairman of the California Energy Commission, testified that:

> "The federal government must continue to be a pivotal player in promoting and advancing energy RD&D and energy-related programs. Congress cannot assume that the states will institute or continue RD&D programs as utilities cut back or eliminate RD&D programs. After averaging about $135 million a year for both electricity and gas RD&D prior to restructuring, California's PIER [Public Interest Energy Research] Program is funded at $62 million per year. Similarly, energy efficiency programs averaged $450 million a year prior to restructuring and now are funded at $240 million."

3. Clean Energy for a Cleaner Environment

Research and development of clean energy technologies will result in reduced carbon intensity, greater diversity of domestic energy supplies, opportunities for technology exports, improved U.S. competitiveness, and little or no environmental damage. A wide range of improved clean energy options -- renewable, fossil, and nuclear -- could be introduced and widely deployed within the next two decades. These can begin to match the carbon reduction impact of increased end-use efficiencies within this period.

DOE energy R&D technology pathways to address *carbon intensity* will seek to move the energy mix towards lower emissions of all types. Power generation with advanced turbines and combined cycle plants, industrial applications, and the long term potential to tap oceanic gas hydrates will result in the increased use of natural gas. The potential of renewable energy to address our multiple energy goals is enormous. Expanded R&D will continue the steady progress made since 1980 in reducing their costs and improving performance. DOE is pursuing a balanced R&D portfolio in close collaboration with industry that includes solar photovoltaics, solar thermal, biomass combustion, wind, geothermal, hydrogen and several enabling technologies such as superconducting materials. The FY 1999 budget request for renewable energy technologies of $342 million (excluding transportation biofuels) will result in substantial R&D progress that will make several technologies competitive in the marketplace in the very near term; wind power is already supplying over three billion kilowatt hours of electricity to the grid. It will also accelerate the pace of technical improvements in photovoltaics, demonstrate the technical merit of co-firing biomass with coal, and lower the cost of geothermal energy.

Cleaner coal technologies with higher efficiencies will eventually double the energy per unit of fuel use, dramatically reducing carbon dioxide emissions as well as other pollutants such as nitrogen oxides, sulfur dioxide and particulate matter. Coal currently accounts for 55 percent of the electricity generated in the United States. Virtually every credible forecast of future power generation indicates that coal will continue to be the dominant fuel source for electricity generation well into the next century, accounting for at least half of the Nation's electricity generation.

DOE is developing a portfolio of advanced technologies that ultimately will culminate in the "Vision 21 EnergyPlex" concept. "Vision 21" reflects a new approach to 21st century energy production by integrating cost-effective, high-efficiency technologies into a single, fuel-flexible facility capable of co-producing electric power, process heat, and high-value fuels and chemicals while minimizing. The concept builds on DOE's existing R&D programs in advanced coal and biomass gasification, gas cleanup, next-generation fuel cells, and high-performance turbine technology. It also includes the R&D needed for key enabling technologies, such as low cost oxygen separation, advanced hydrogen separation membranes, high temperature ceramic heat exchangers, and, potentially, carbon dioxide capture and disposal technologies. Developing the "Vision 21" concept will also require advances in materials and components, new catalysts and sorbents, and, to minimize the costs of engineering scale up, the use of advanced computational technology to test "virtual pilot/demonstration configurations."

DOE is developing the following coal-based power generation systems: Low-Emission Boiler systems, Pressurized Fluidized Bed Combustion, Integrated Gasification Combined Cycle and Indirectly Fired cycles. The coal-fired power plant of tomorrow may also incorporate advanced sub-systems such as super clean flue gas scrubbers or perhaps over the longer term, innovative techniques for removing carbon dioxide. Fossil energy research is supporting programs to develop these future high tech devices: Super-Clean Emission Control Devices, Air Toxics Emission Control, CO_2 Recovery, Reuse and Disposal and Solid Waste Management. These technologies are expected to reduce greenhouse gas emissions by 40-47 percent compared to currently deployed systems.

Natural gas also can play a much greater role in the electric generation sector. As much as 50 percent of the growth in demand for natural gas through 2010 is expected to be in the power generation market. Gas-fired generating units, particularly combined cycle systems, are more efficient and less capital intensive than other alternatives, have lower non-fuel operating costs, and can be constructed with shorter lead times with smaller, economically sized units. We also have an Advanced Power Systems effort that includes advanced gas turbines and fuel cells. These technologies offer reductions of 60-65 percent in greenhouse gas emissions compared to a conventional coal-fired power plant.

Nuclear power plants generate electricity without producing carbon dioxide, sulfur oxide, or nitrogen oxide emissions. Consequently, the FY 1999 budget proposal includes two modest initiatives aimed at sustaining nuclear energy as a viable option, despite the considerable uncertainties. First, the Nuclear Energy Plant Optimization program is the Department's response to the PCAST recommendation that the Department initiate a program of research aimed at operating nuclear power plants. The proposed program would develop the technologies needed to improve capacity factors of existing U.S. plants. Second, the Nuclear Energy Research Initiative is a program that features an independent, competitive, peer-reviewed process for selecting from among investigator-initiated R&D proposals. This program will fund work in areas such as advanced nuclear fuel, proliferation-resistant reactor systems, and lost-cost, advanced power systems.

4. Carbon Sequestration: Maximize Resources, Minimize Environmental Impacts

In contrast to the pathways discussed already, the benefits of carbon sequestration R&D are focused particularly on our climate change goals. Carbon sequestration is the removal of atmospheric carbon through natural or induced methods. The dominance of fossil fuels in our energy portfolio suggests the importance of this high-risk, high-payoff research. Technology breakthroughs in sequestration could prove to be a major benefit for the domestic coal industry, for the creation of international markets, and for minimizing coal impacts on the environment. Research and development on this pathway is at its early stages of exploration and large scale impacts are not anticipated for decades.

Carbon Sequestration Basic Research. The Department has requested $9 million in FY 1999 for the Energy Research budget to better understand the scientific aspects of carbon sequestration. Implementing carbon sequestration on the scale needed to impact the global CO_2 budget requires new levels of understanding -- from the molecular to ecosystem scale -- about the geological, chemical, physical and biological interactions between carbon and the environment.

Each year, on the order of 100 Gigatonnes of carbon cycle between the atmosphere and terrestrial biosphere, demonstrating a large potential for both capturing and sequestering carbon. Slowing the release of CO_2 back to the atmosphere could have a large impact on the global CO_2. This strategy of altering the natural carbon cycle requires much better understanding of the chemical, physical, and biological processes that regulate CO_2 exchange between the atmosphere and the terrestrial biosphere. This research would investigate the biological capture of atmospheric CO_2 by plants and soils and determine how quantities might change naturally or through bioengineering.

Before long-term underground sequestration can be considered seriously, there are many scientific questions that must be addressed. How much CO_2 can be safely stored in subsurface reservoirs? What are the effects of high pressure CO_2 injection on the geo-mechanics of different rock formations? At what rates will the injected CO_2 react with different rock formations and how will this affect the fluid flow in these formations? The answer to these and other questions will be needed before underground sequestration becomes a reality. Similarly, research is needed about the full range of processes that influence carbon capture at the ocean surface and the transmission of the carbon to deep ocean reservoirs.

Carbon Sequestration R&D. A complementary approach to sequestration research involves developing technological pathways. There is currently a limited program within the Office of Fossil Energy (about $1.6 million in FY 1998) to develop and demonstrate technically, economically, and ecologically sound methods to capture, reuse and dispose of CO_2 to investigate sequestration technologies. This program involves collaboration with 17 countries through the International Energy Agency Greenhouse Gas Program, which includes work such as monitoring the CO_2 that has already been injected into an aquifer in the North Sea.

In FY 1999, the Department is requesting to expand this program to $10 million in three areas of research. The first category would be geared to "traditional" research, that is putting captured CO_2 from power plants into geological formations such as depleted oil and gas wells, unmineable coal seams and aquifers or into the deep ocean. The second category is best described as "enhancing natural sinks," for example, enhancing the growth of forests and algae, which, in turn, would enhance their uptake of CO_2. This program will be coordinated closely with the Energy Research program on enhancing natural terrestrial sinks. The third category entails investigator-initiated proposals that may lead to novel breakthrough technologies.

5. Basic Research

Essential to our work in each of these areas discussed above is the Department's continued investment in the basic sciences. While the results of basic research are difficult to predict with any accuracy, the evolving understanding of the important nonlinearities and feedback loops in the science of global systems will help guide climate change strategies, and basic research breakthroughs, from materials science to bioscience, should yield novel technologies for mitigating environmental consequences of energy use.

The basic science of the greenhouse effect is well established. Indeed, the 60 degree Fahrenheit average warming produced by the "natural" greenhouse effect is essential to life on earth. Further, even the temperature rise associated with increased CO_2 concentration in the atmosphere was predicted quite well more than a century ago. In the last years, more extensive data collection and the power of large scale simulation have refined the predictions considerably and have yielded insights into the consequences of global warming -- from global consequences such as sea level rise to more regional phenomena affecting the weather, agriculture and human health. Understanding the latter quantitatively clearly requires more research. The potentially catastrophic consequences in the next century of continued greenhouse gas emissions clearly should not be ignored either in our research portfolio or in the policy signals sent by government.

The Department of Energy is the third largest contributor to the overall U.S. Global Change Research Program. In support of the U.S. Global Change Research Program, DOE's Energy Research program includes research in climate modeling, atmospheric chemistry and transport, atmospheric properties and processes affecting the Earth's radiant energy balance, carbon sources and sinks, consequences of atmospheric and climatic change for vegetation and ecosystems, critical data needs for global change research and for early detection of climatic change, and funding for education and training of scientists and researchers in these areas. The ongoing research to understand the global carbon cycle is critical to selecting optimal strategies and technologies to arrest climate change and to implementing and monitoring international climate change agreements in the future.

Under the Administration's Climate Change Technology Initiative, the basic research program will also address science for efficient technology and low-carbon energy supply, in addition to the sequestration science that I referred to earlier. Some promising areas with an energy impact include: biosciences, with the potential to grow fuel crops and tailored industrial feedstocks; photoconversion technologies for the production of very cheap electric power or fuels directly from sunlight; and understanding of the global carbon cycle in order to select optimal strategies and technologies to arrest global warming.

DOE's proposed energy research program builds on ongoing, complementary research in related fields. Some of the broad research tools under development by the Department, for a variety of mission areas, will have a significant impact. For example, fundamental materials science will be used to develop low-friction, lightweight, and nano-scale materials that improve energy efficiency; biomimetic (biological-mimicking) chemistry, biochemistry, and molecular genetic sequencing of microbial organisms that produce methane and hydrogen will promote low-and non-carbon emitting energy sources; and, catalysis research will be used to advance energy efficient chemical processes. The powerful Spallation Neutron Source proposed for construction in the FY 1999 budget will greatly enhance American materials science capabilities. The new scale of computational and simulation power under development for stockpile stewardship will also permit much higher resolution studies of the global atmosphere-oceans-ecosystem coupled system. These studies will be especially important for assessing local and regional ecological impacts of increased atmospheric greenhouse gas concentrations.

PUBLIC INVESTMENT IN ENERGY R&D

Competitive markets are the cornerstone of successful energy policy. Government can and should address the inherent limits of private markets to ensure that energy security, environmental quality and energy research -- those societal benefits most often undervalued by the private sector -- are adequately addressed.

A recent *Business Week* column on PNGV illustrated the government's role in R&D this way: "Government financing of pre-competitive research was necessary because auto makers, as rivals looking to near-term results, simply could not commit enough funds for a sufficiently long time horizon." The column went on to describe the result of this collaboration: ". . . at the mid-point of the 10 year effort, the alliance is paying real dividends. The progress, Detroit recently claimed, would not have occurred without a government policy commitment to clean air. Washington deftly used the CAFE standards as a stick and the PNGV as a carrot."

While the need for investment is clear, the current funding profile for both public and private investment in energy R&D is cause for concern. The PCAST report states that the DOE R&D budgets have declined five fold in real terms between 1978 and 1997. Trends in private sector R&D investment mirror this decline in public sector investment. PCAST also found that " . . . industry's spending for R&D fell 40 percent in real terms between 1985 and 1994 . . . the R&D spending of the 112 largest U.S. operating electric utilities fell 38 percent between 1993 and 1996 alone and the R&D for the four U.S. oil firms with the largest research efforts approximately halved between 1990 and 1996."

DOE is cognizant that our dollars must be spent carefully. Our overall technology strategy involves extensive work with private sector partners to assure that our programs are relevant, the government role is appropriate, and that a payoff is in sight. By focusing our investments in areas where private resources are lacking, such as our computational and simulation tools, and where there is a potential to realize substantial public benefits, we can better ensure that we are targeting our efforts appropriately and leveraging resources to the extent possible. In testimony delivered before Congress earlier this year, Lewis Edelheit, Senior Vice-President for Corporate R&D at General Electric, underscored the value of a targeted government role in energy R&D, noting that "Industrial R&D tends to operate within a fairly narrow risk/reward window. Government programs can expand that opening." He also illustrated what he termed the "galvanizing effect" that the Federal government has on energy R&D, citing DOE's collaboration with industry on the Advanced Turbine System program as an example of "... helping industry make advances that would have been much slower in coming, or may not have happened at all, without this government-industry collaboration."

The Federal role logically diminishes as technologies approach commercial viability. For example, DOE played a major role in the 1970's and 1980's in developing atmospheric fluidized bed combustion, one of the most significant advances in clean coal burning technology. As technical issues were resolved and the technology gained market acceptance, DOE's role ended. The federal role should also change when our private sector partners signal that programs are not working or that we should re-focus. For example, in our "Industries of the Future" program, we are concluding efforts with the petroleum refining industry due to lack of progress in developing a technology roadmap to guide future work. Finally, it is the nature of R&D that some seemingly good ideas never achieve their original promise. When this occurs, we must be willing to shift resources, as we did when our research on gas turbines failed to progress sufficiently toward meeting design goals.

The numerous R&D successes, along with the key role energy plays in the economy, environment and national security, prompted the PCAST in its recent report to recommend significant increases in public funding of energy research and development in energy efficiency and renewables, as well as fission, fusion, carbon sequestration and fuel cells. Our FY 1999 budget request is broadly consistent with the PCAST recommendations, both in overall resources and R&D priorities.

DOE ENERGY R&D MANAGEMENT IMPROVEMENTS

We must carry out our responsibilities with sound strategic management of a broad portfolio of energy investments. We are now advancing our strategic management of R&D by:

- *Increasing the profile, expanding the responsibilities and improving the accountability of the DOE R&D Council.* The Council, which I now chair, has a new charter, to more fully integrate and manage the Department's R&D both within and across program areas. The Energy Resources working group of the R&D Council simultaneously serves as a working group of the Energy Resources Board; this will provide a way to fully integrate energy R&D into the development of overall energy policy.

- *Accelerating contract reform and increasing competition.* The Department recently competed the Brookhaven National Laboratory contract for the first time in fifty years and are in the process of competing the M&O contract for the National Renewable Energy Laboratory in Colorado. We must increase competition where appropriate and, at the same time, make certain we provide our laboratories with the levels of stability and management certainty needed to foster creativity and progress.

- *Updating the way we select R&D performers.* We will be intensifying our evaluation of how we award grants and contracts, including technology transfer and partnership agreements, to ensure they are made on the basis of sound scientific review and economic judgment. We need to constantly evaluate the appropriateness of these agreements on a case-by-case basis and make policy and process adjustments when necessary.

Science and Technology "Roadmaps"

Science and technology "roadmaps" address specific problems and needs by defining goals, engaging in a consensus building process with stakeholders, and developing R&D plans most likely to achieve success. R&D road maps have been successfully employed by the private sector -- the semiconductor industry roadmap is a good example -- and we are currently seeking to expand use of this discipline in the Department of Energy. Technology roadmaps will define our travel along the technology pathways described earlier.

Technology road maps will serve as a primary tool with which to "strategically manage" the cross-cutting R&D needs and capabilities of the Department. Let me give you some examples. By partnering with the DOE's Office of Industrial Technologies in a road mapping exercise, the aluminum industry has taken significant steps in planning for its technology needs for the next twenty years. Over the next year, the development of a more detailed aluminum industry research agenda will help to realign, if necessary, research to be conducted by companies, universities and the national laboratories. The aluminum industry is now working to make certain it understands the needs of its end use customers. It is anticipated that this roadmap will be periodically revised and updated to reflect changing markets and technical issues and to ensure that research priorities continue to reflect customer needs.

More broadly, industry, partnering with DOE, has developed long-term visions for six energy intensive U.S. industries -- steel, aluminum, chemicals, pulp and paper, glass and metal casting -- of energy efficient, low-polluting, highly competitive "Industries of the Future," as well as technology roadmaps to identify an R&D and deployment pathway to achieve this vision. A prototype Clean Power roadmap is also being jointly developed by our Offices of Fossil Energy and Energy Efficiency and Renewable Energy.

The R&D Council has directed that each DOE business line developed present for review roadmaps in key areas. We recognize that "one size will not fit all." But by encouraging the development of roadmaps that connect program objectives with a "bottom-up" scientific and technical definition of problems, we can better define, review, improve and adapt plans to accomplish our often highly complex missions. The process is moving forward with full cooperation from the national laboratory directors.

CONCLUSION

Mr. Chairman, DOE's FY 1999 budget will put us on an energy R&D track that will address our shared goals of economic, national, environmental and energy security. It also represents a prudent response to the challenge of global warming that will result from a worldwide "business as usual" approach to energy production and use.

The climate change issue clearly demands the attention of government -- not in spite of remaining uncertainty with regard to regional ecological and human health impacts, but *because* of it. A strengthened energy science and technology program, together with synergistic tax incentives for accelerated technology introduction, is an important first step with multiple benefits for America. A recent *Washington Post* editorial on the Administration's FY 1999 budget proposal put it this way:

> ". . . this [global warming] proposal would make sense whether Kyoto ever comes into force or not. Most of the initiatives would spur industry toward pollution-reducing measures that will benefit the country and make industry more competitive in the long run. Indeed, those who oppose binding commitments, trading permits, increased fuel taxes and more regulation should, more than anyone else, embrace measures that might produce progress without coercion."

In a similar vein, the PCAST panel unanimously advocated a substantial and sustained increase in the energy R&D portfolio despite a lack of consensus on the consequences of global warming.. A central reason that PCAST noted in this respect is that:

> ". . . many of the energy-technology improvements that would be attractive for [greenhouse gas reduction] also could contribute importantly to addressing some of the other energy-related challenges that lie ahead, including reducing dependence on imported oil; diversifying the U.S. domestic fuel and electricity supply systems; expanding U.S. exports of energy-supply and energy-end-use technologies and know-how; reducing air and water pollution from fossil fuel technologies; reducing the cost and safety and security risks of nuclear energy systems around the world; fostering sustainable and stabilizing economic development; and strengthening U.S. leadership in science and technology."

The Department of Energy's missions are linked by the common thread of science. Our public investment in energy research and development is a key catalyst for insights and advances on many fronts -- increasing our energy security, private sector innovation, and expanding markets. In addition, these same resources contribute to expanding our future options by reducing environmental impacts of energy use -- locally, regionally, and globally.

This Administration and the Department of Energy, with the support of the Congress, can provide a large measure of the scientific and technological leadership our nation needs to maintain its preeminence in the global marketplace and our commitments to a cleaner, safer world.

I look forward to working with the Committee to advance our nation's key energy R&D programs. Thank you for your attention and I would be pleased to address any questions.

U.S. Department of Energy
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202/586-3640

BIOGRAPHY

ERNEST J. MONIZ

Dr. Ernest J. Moniz was unanimously confirmed by the U.S. Senate as the Department of Energy's new Under Secretary on October 28, 1997. As the Under Secretary, Dr. Moniz advises the Secretary regarding science and technology research and development, including energy efficiency, environmental technologies, national security, and fundamental research. Dr. Moniz's research and development expertise serves the Department well in its vital missions of stockpile stewardship, environmental preservation, energy security and scientific innovation.

Dr. Moniz is committed to excellence in science education and comes from an academic background himself. Most recently, he was a Professor of Physics and Head of the Department of Physics at the Massachusetts Institute of Technology, where he was responsible for the research and educational programs of the department. Prior to that, he served as the Associate Director for Science in the Office of Science and Technology Policy at the Executive Office of the President. He was nominated to this position by President Clinton in June 1995 and was responsible for overseeing matters relating to science education and university-government partnerships. In addition, Dr. Moniz advised the President regarding physical, life, social and behavioral sciences. Dr. Moniz also consulted on the Clinton Administration's 1994 science policy statement, *Science in the National Interest*.

Dr. Moniz's principal research interests are in theoretical nuclear physics. He joined the MIT faculty in 1973 and served as the Director of the Bates Linear Accelerator Center from 1983 to 1991. The Center is a nuclear physics research facility operated by MIT for the Department of Energy. Dr. Moniz is widely recognized for his work in describing the interaction of pions with nuclei.

Dr. Moniz has served numerous universities, national laboratories, professional societies, and government agencies in advisory roles. For example, he served on the American Physical Society Study Panel for Nuclear Fuel Cycles and Waste Management. He has provided scientific program advice for several particle accelerator laboratories in both the United States and Europe and served as Chairman of the Director's External Review Committee for the Los Alamos National Laboratory Physics Division. From 1992 to 1995, Dr. Moniz served the Department of Energy and the National Science Foundation as the Chairman of the Nuclear Science Advisory Committee, leading long-range planning for American nuclear physics.

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Dr. Moniz received a Bachelor of Science degree in physics from Boston College in 1966 and a doctorate in theoretical physics from Stanford University in 1971. With a postdoctoral fellowship from the National Science Foundation, Dr. Moniz performed research at the Centre d'Etudes Nucleaires de Saclay in Gif-sur-Yvette, France and at the University of Pennsylvania during 1971 to 1973.

Dr. Moniz is a Fellow of the American Association for the Advancement of Science, the Humboldt Foundation, and the American Physical Society.

November 1997

Chairman SENSENBRENNER. Thank you very much. The next witness is the Honorable David M. Gardiner, Assistant Administrator for Policy, Planning, and Evaluation of the EPA. Mr. Gardiner, I would appreciate it if you could confine your remarks to 5 minutes so that we will have time for questions by members of the Committee.

TESTIMONY OF THE HONORABLE DAVID M. GARDINER, ASSISTANT ADMINISTRATOR FOR POLICY, PLANNING AND EVALUATION, U.S. ENVIRONMENTAL PROTECTION AGENCY, WASHINGTON, DC

Mr. GARDINER. Thank you, Mr. Chairman. I appreciate the opportunity to be here this morning.

I think you have heard already from Dr. Gibbons about the compelling view that we have of the science on this issue and the potential impacts of climate change. And because those effects are potentially so serious and so costly to us and to others around the world, and to help the country meet the challenge of global warming, the President, as you all know, proposed in October that we launch an initiative to invest in research and development. And, specifically in the budget, he has now proposed a Climate Change Technology Initiative that will invest $6.3 billion in R&D and targeted tax cuts over the next 5 years and lead to multiple environmental and economic benefits. The Administration's—I would also note that the Administration's—current climate change program is already reducing greenhouse gas emissions, and the President's initiative will do even more.

I wanted to make two fairly straightforward points this morning, the first of which is that the investments proposed by the President will bring economic benefits beyond those associated with the control of global warming. They will provide incentives for American businesses and communities to cut greenhouse gases now, in ways that make economic sense now. They will speed the adoption of today's cost-effective, energy-efficient, low-carbon technologies throughout the economy and hasten the development of even more advanced technologies in the future. Using energy more efficiently in our businesses, homes, and vehicles will save money and make our overall economy far more productive, while at the same time reducing emissions of greenhouse gases and other pollutants.

We've already seen how effective these kinds of incentives can be. Under our current climate change programs, the Administration has negotiated voluntary partnerships—and I would emphasize voluntary partnerships—with thousands of U.S. businesses and others that will cut greenhouse gas emissions while at the same time slashing annual U.S. energy costs. Dozens of companies like General Motors, IBM, Motorola, and Lockhead Martin are cutting energy use, saving money, and reducing their emissions of greenhouse gases.

Just to pick one example, the Dupont Company alone has taken steps to cut energy use that has saved the company $31 million in 1995 alone while reducing their greenhouse gas emissions by 18 million tons by the Year 2000.

These voluntary programs will be continued and expanded under the President's proposed climate change initiative. And at the Environmental Protection Agency, we'll have a particular focus on the building sector, the industrial sector, transportation, and a number of cross-cutting issues.

All of these investments will help enhance the productivity of the American economy. All of these investments will help American businesses compete more effectively in the global economy. All of these investments will reduce emissions of greenhouse gases and move us closer to the goals of reducing the threat of global warming.

And while as good as that sounds, it's not as good as it gets. And this is the second point I wanted to make, and that is that every dollar we invest to improve energy efficiency and to reduce the emissions that cause greenhouse gases—or the greenhouse problem—will control other pollutants beyond greenhouse gases.

The combustion of fossil fuels is also a major source of conventional air pollutants like particulates, nitrogen oxides, volatile organic compounds, and carbon monoxide. These pollutants, as you know, have been linked conclusively to heightened risks of mortality, chronic bronchitis, congestive heart failure, heart disease, and other serious illnesses. Children and the elderly are most vulnerable to these pollution-related illnesses. Thus, many of the actions that we take to combat climate change in the short term and in the long term will bring immediate public health benefits in the form of cleaner air and cleaner water. One peer-reviewed study estimates that in the Year 2010, greenhouse gas controls could save 20,000 lives in the United States, and more than 200,000 lives worldwide, because of related reductions in particulate emissions alone. Controls on greenhouse gases could lead to improved viability, more and better recreational opportunity, and reduced nitrogen deposition in vulnerable water bodies like the Chesapeake Bay.

In 1999, alone, EPA's global warming programs are expected to reduce nitrogen oxide emissions by 90,000 tons per year, thus improving both air and water quality. And we would expect under the Climate Change Technology Initiative even greater emission reductions in the future.

So what we're talking about here is a cost-effective, commonsense approach to a serious problem. The tax credits and other programs in the President's proposed Global Warming Initiative will reduce the health and ecological problems caused by the greenhouse effect, they will help the economy to grow by making it more energy efficient, and position the United States to prosper even more in the global market place as other countries look for technologies to reduce these emissions, and they will bring substantial ancillary health benefits by reducing emissions of conventional pollutants like particulates and nitrogen oxides.

This is an economically sound and environmentally sensible approach. And we look forward to working with the Congress, the business community, and the American people as we move forward in our efforts to control climate change and provide a better quality of life for all of our people.

Thank you, Mr. Chairman.

[Mr. Gardiner's prepared statement and biography follow:]

TESTIMONY OF
DAVID M. GARDINER
ASSISTANT ADMINISTRATOR FOR
POLICY, PLANNING AND EVALUATION
U.S. ENVIRONMENTAL PROTECTION AGENCY
BEFORE THE
COMMITTEE ON SCIENCE
UNITED STATES HOUSE OF REPRESENTATIVES

February 12, 1998

Mr. Chairman, and Members of the Committee, thank you for this opportunity to testify on the Administration's plans to address global warming. Our goal is to develop, in consultation with the Congress and the American people, international and domestic strategies to address global warming that are environmentally sound and economically sensible.

I am pleased to report that we have made substantial progress towards that goal in the last several months. On October 22 of last year, President Clinton announced his climate change proposal. He described the Administration's international negotiating goals and our plans to move ahead to address climate change domestically. In December, U.S. negotiators reached agreement with other nations on the Kyoto Protocol. Although more work remains to complete the agreement, it bears the unmistakable imprint of U.S. demands for realistic targets and timetables, coverage of all greenhouse gases, national flexibility and market-based mechanisms for control. Finally, just last week in his budget announcement, the President unveiled the Climate Change Technology Initiative, a $6.3 billion, five-year package of tax credits and investments in technology that make sense right now and will put the Nation on a smooth path to meeting our international obligations.

Decisions on what to do about any environmental problem *begin* with the science. The President's Science Advisor, Dr. Jack Gibbons, has given the Committee a comprehensive presentation of the scientific evidence for global warming and for the broad range of serious adverse impacts that lie in wait for us if we do not begin to reduce greenhouse gas emissions. Let me emphasize several points that are particularly important from the standpoint of the Environmental Protection Agency, which is charged with the responsibility to protect the health and the environment of the American people.

First, global warming endangers Americans' health, especially the health of our children, grandchildren, and future generations. Unless we begin to act:

- According to the Intergovernmental Panel on Climate Change, representing 2,000 leading scientific experts from around the world: "Climate change is likely to have wide ranging and mostly adverse impacts on human health, with significant loss of life."
- There will be more frequent and more intense heat waves. Deaths directly attributable to heat waves in the U.S. could more than double by the middle of the next century.
- Hotter weather may lead to more frequent and more intense smog episodes, causing more deaths and illnesses from air pollution.
- Pest-borne tropical diseases may spread across our borders as warmer temperatures expand the range of disease-carrying insects and rodents.
- There will be more frequent and severe droughts and floods, causing deaths and injuries, as well as huge property losses.
- Sea level will rise, exposing coastal areas to higher storm surges, with greater threats to health and safety, and more property damage. Salt water intrusion into coastal aquifers will endanger the drinking water supplies for millions of Americans.

Second, global warming endangers Americans' environment. If we do not act, our children and grandchildren will see our forests, rivers, and other natural resources stressed and threatened as never before.

- By the end of the next century, rising sea le could drown 4000 square miles of our ecologically-critical coastal wetlands. Five ti. ısand square miles of dry land in states like Louisiana and Florida could be lost under water.

- Trout and other fish species could be entirely wiped out in many states -- depriving millions of our children and grandchildren of the simple pleasures of fishing.

- Forests and habitats will be lost in many states as climatic ranges shift faster than plant or animal species can migrate. Maple trees could die out in the Northeast, wiping out the fall colors of New England forever. Glaciers may disappear from Glacier National Park. About one-third of the Florida Everglades, now being protected at significant cost, has an elevation of less than 12 inches and is highly vulnerable to sea level rise.

Third, health and environmental impacts such as these will have profound economic costs as well. Simply put, if we do not act, global warming will threaten the cleaner and healthier air, water and natural resources which the last six Presidents and 14 Congresses have worked so hard to restore and protect. We cannot allow this to happen.

In short, the immense threat posed by global warming is why the achievement in Kyoto is so important. Without repeating the detailed explanation of the Kyoto Protocol this Committee heard last week, I would note only that the Kyoto agreement embodies our key proposals for an achievable target on a realistic timetable, maximum national flexibility, and maximum use of market-based implementation tools. The agreement allows American businesses and consumers a decade of lead-time to adopt the technologies and practices needed to meet our emissions target. The agreement also includes the flexibility of a five-year budget period, covers all six important pollutants (allowing the flexibility of greenhouse-gas trade-offs), and includes three forms of international market-based emissions trading. The agreement rejected proposals by other countries for overly ambitious targets, unattainably short deadlines, and inflexible mandatory policies and measures.

To be sure, there is much more work to be done. In the coming year and beyond, we will work with other nations, both multilaterally and bilaterally, to fill in key implementation details and to obtain greater participation from key developing nations.

The question before us now is what should be done domestically while we pursue this agenda for further international work. Some may say that we should do nothing at all at home until all countries are fully on board and all the details are filled in. But such a course has two big drawbacks.

First, there are many voluntary steps to cut greenhouse gas emissions that make complete economic sense to undertake now, regardless of any international agreement. Improving the energy-efficiency of our businesses, homes, and vehicles and taking other steps to reduce greenhouse gas pollution can save large amounts of money and make our economy more productive.

Second, reasonable people who differ on the need for the Kyoto Protocol can still agree that it would be prudent to use the decade of lead-time provided by the Protocol to take reasonable steps to reduce greenhouse gas emissions that have numerous other benefits to the economy and the environment, and that will best position American businesses and the American economy for further action as the science evolves.

Third, as the most innovative economy in the world and the largest contributer to greenhouse gas pollution, the United States must take the lead in responding to this immense global environmental threat. By acting, and not just talking, we can assume moral leadership, send an important market signal to the rest of the world, and make it easier to recruit other nations to do their share.

That is why last October President Clinton proposed the Climate Change Technology Initiative (CCTI). The President has proposed $6.3 billion in targeted tax cuts and program investments over five years to speed the adoption of today's cost-effective energy-efficient and low-carbon technologies throughout the economy, and to hasten the development of even more advanced technologies for tomorrow.

Through our current programs implemented under the 1993 Climate Change Action Plan (CCAP), EPA and the Department of Energy (DOE) are already helping American businesses and consumers save money by employing energy efficient technology when replacing obsolete equipment or expanding. These technologies also can often enhance businesses' overall productivity.

The latest example, announced by Vice President Gore last month, is the new "Energy Star" partnership, under which the major TV and VCR manufacturers will make products that use less energy. Your current TV uses energy even when it is turned off as circuits respond instantly when you press the remote control. The new machines will sharply cut the amount of energy used when off, reducing pollution by up to a million tons of carbon per year, and saving consumers up to $500 million per year on their electric bills. TVs and VCRs with the "Energy Star" label soon will be in stores across the country.

EPA's existing CCAP programs are expected to reduce U.S. greenhouse gas emissions by more than 40 million tons of carbon equivalent (MMTCE) in 1999. EPA's partnerships are expected to reduce annual U.S. energy expenditures by more than $25 billion by 2010. The

President's Climate Change Technology Initiative includes funds for EPA to expand these technology deployment partnerships to reach more businesses and consumers, and to cover more products and technologies. The CCTI also includes funds to carry out the President's call for industry-by-industry consultations to develop voluntary but aggressive strategies to reduce emissions of greenhouse gases.

At EPA, we know from experience that voluntary and partnership programs work. Several recent successes demonstrate the potential from these approaches:

- *Aluminum Industry Partnership.* EPA has forged agreements with 90% of the aluminum industry to reduce their emissions of perfluorinated compounds (PFCs), which are potent greenhouse gases, by 40-60% by 2000. With key technical support from EPA, the companies are well on their way to meeting their commitments.

- *Metal Finishers Agreement.* Through EPA's Common Sense Initiative, the metal finishing industry has committed to improving energy efficiency by 25% by the year 2002, while reducing other toxic chemicals.

- *Green Lights and Energy Star Buildings.* U.S companies and organizations joined EPA's Green Lights and ENERGY STAR Buildings Programs, they could reduce the carbon dioxide emissions due to the energy used in commercial buildings by 35 percent and reduce commercial buildings' energy bills by $25 billion per year.

- **Quad Graphics, Pewaukee, WI.** Through EPA's Green Lights program Quad Graphics has installed energy efficient lighting in its buildings, preventing more than four thousand tons of carbon dioxide emissions -- equivalent to eliminating the emissions of more than 1,000 cars. The company is saving more than $250,000 every year on its energy bills -- and enjoying better lighting quality.

- **New York State.** These opportunities are available not only to private companies, but to all types of organizations. Through EPA's Energy Star Buildings and Green Lights programs, the State of New York is currently saving New York taxpayers more than $2.5 million per year on state energy bills, while preventing more than 16 thousand tons of carbon dioxide emissions.

- *Climate Wise.* Since 1994, 392 companies, representing 8.5% of U.S. industrial energy use, have joined Climate Wise, including: British Petroleum, DuPont, 3M, Johnson & Johnson, General Motors, Boeing and more than 200 small and medium-sized companies.

Companies have submitted Action Plans detailing more than 700 emissions reductions actions that they estimate will reduce greenhouse gas emissions by more than 5 million metric tons of carbon equivalent by the year 2000. In the process they expect to save more than $300 million. Here are some examples of what they're doing:

- **General Motors** reduced more than 54,500 metric tons of carbon per year by switching to natural gas at five steam-generating facilities. In addition, the first of 11 facility energy audits has identified procedural changes and projects saving 19% of total energy use.

- **DuPont** estimates that its actions will reduce emissions of greenhouse gases equivalent to 18 million metric tons of carbon dioxide by the year 2000. DuPont's energy efficiency improvements include switching boiler fuels, improving steam balance, decreasing waste heat and optimizing system performance in aeration blowers. Energy efficiency actions saved the company $31 million in 1995 alone.

- **IBM** estimates that their energy efficiency projects will reduce greenhouse gas emissions by 60,000 metric tons and save the company $5.5 million in the year 2000. Their actions include changes in process and facility design and improvements in energy metering and monitoring that will help them to better identify energy efficiency opportunities.

- **Motorola-Austin** reduced annual carbon emissions by more than 4,740 metric tons per year and saved more than $1 million in 1996 alone by optimizing the performance of their boilers, insulating steam lines and repairing faulty insulation.

- **Lockheed Martin** estimates that it will achieve annual cost savings of $175,000 and prevent the emission of 1,750 tons of carbon dioxide each year by committing to efficiency measures including boiler and process cooling efficiency, and the development of an energy automation program at facilities around country.

The Initiative also includes additional resources for research and development in key areas of energy-efficient technology. These R&D resources will allow EPA to accelerate its work under the Partnership for a New Generation of Vehicles (PNGV) to help develop cars and light trucks that get three times the fuel economy of current models, with comparable performance, safety, amenities, and cost. Working with industry and with DOE and other agencies, we will also undertake a partnership to develop delivery and long-haul trucks that achieve significantly greater fuel economy while meeting stringent emissions targets.

The Initiative also includes $3.6 billion over five years in targeted tax cuts to help businesses and consumers buy and adopt these technologies.

- Tax credits for highly fuel efficient vehicles: This credit would be $4,000 for each vehicle that gets three times the base fuel economy for its class beginning in 2003. A credit of $3,000 would be available beginning in 2000 for vehicles that get double the base fuel economy for its class. These credits would be available to jump start these markets and would be phased out over time.

- Tax credits for energy efficient equipment: These credits (all of which are subject to caps) would include a 20% credit for purchasing certain types of highly efficient building equipment, a 15% credit for the purchase of rooftop solar systems, and a 10% credit for the purchase of highly efficient combined heat and power systems.

Under the CCTI, EPA will expand its efforts in each sector of the economy in order to target the key opportunities for win-win emissions reductions that protect the environment while promoting economic growth. Key areas where EPA is expanding its efforts include the following:

1. Industry Initiatives -- the President has invited entire industries to work with the Federal government and develop greenhouse gas plans. In addition to its partnerships with individual companies, EPA will consult with key industries to develop voluntary but aggressive strategies for further greenhouse gas reductions that improve overall productivity and promote the deployment of clean technologies such as the use of industrial combined heat and power, and to build a program that appropriately rewards early action. EPA will seek dialogue with key stakeholders throughout industry and the NGO community.

2. Transportation Initiatives -- EPA will accelerate its efforts under the Partnership for a New Generation of Vehicles (PNGV), and will develop enabling technology for production

prototypes for delivery and long-haul trucks that would achieve significant increases in fuel economy while meeting stringent emissions targets. The National Academy of Sciences has determined that EPA's renewable fuels application for 4SDI engines is the lead PNGV candidate technology. When complete, EPA's design will provide the basis for a viable and proven concept vehicle for commercialization. It will also provide a strong technical base from which to initiate additional EPA research into similar technologies for light truck application. EPA will also expand its work with state and local decision-makers to develop and implement transportation improvements that encourage "livable communities" -- compact, walkable and mixed use development -- while reducing the growth in vehicle travel, emissions, and congestion.

3. Buildings Initiatives. The buildings sector, which includes both homes and commercial buildings, offers a large potential for carbon reductions using technologies that are on the shelf today. However, consumers and businesses continue to invest substantial resources in equipment that is relatively energy inefficient, resulting in higher energy bills and higher pollution levels. One of the key challenges over the next decade will be to overcome market barriers, such as the lack of reliable information, and improve the markets for energy-efficient products. EPA will expand its partnerships with equipment manufacturers and building owners in order to provide reliable, easily understood information to a greater segment of the residential and commercial markets. EPA will also expand its work to support other Federal agencies in improving the energy performance of their facilities.

4. Carbon Removal. EPA working with the U.S. Department of Agriculture will encourage the forest products sector to achieve greater reliance on biomass fuels as an energy source and be a supplier of carbon sequestration credits through afforestation and reforestation

activities EPA will accelerate efforts to promote the use of livestock based fertilizer products and more efficient use of nutrients from all sources.

5. Crosscutting Analysis and Approaches. To build support for and the institutional capacity needed to implement a domestic and international carbon emissions trading program, EPA will work with developing nations and states and localities. Emissions from developing countries are growing rapidly and are projected to exceed those of developed countries within the next forty years. An effective, efficient global solution to climate change must be market-based and must involve both developed and developing countries. The Administration and EPA will work to secure additional international support for the American vision of global climate protection reflected in the Kyoto Protocol by assisting key developing countries in their efforts to reduce greenhouse gas emissions and address global climate change. EPA will also expand its work with states, which are key players, in efforts to reduce greenhouse gas emissions. EPA will provide support to states to help develop emission inventories and voluntary action plans, and implement and expand promising policy options identified by states in the greenhouse gas mitigation plans.

While these actions are justified on the economics and their contribution to climate change, they also help the environment in other ways. Fossil fuel combustion is not only the major source of US greenhouse gas emissions, but also of conventional air pollutants (e.g., particulate matter, oxides of nitrogen, volatile organic compounds, carbon monoxide, etc.). A vast, peer-reviewed scientific literature has conclusively linked U.S. air pollution with heightened risks of mortality, chronic bronchitis, congestive heart failure, ischemic heart disease, and other serious illnesses. Children and the elderly are the most vulnerable to the effects of poor air quality Thus, if we take these measures to combat global climate change, we will also reap immediate public health benefits in the form of cleaner air and cleaner water Let me give you some examples:

- The Lancet, a highly respected British medical journal, recently published a peer-reviewed study of the particulate matter-related health impacts of fairly aggressive, worldwide greenhouse gas mitigation. The analysis found that an estimated 8 million deaths globally due to exposure to fine particles could be avoided between 2000 and 2020 if substantial steps were taken to limit greenhouse gas emissions from burning fossil fuels. In the United States alone, the study reports that thousands of deaths annually could be avoided during the 2000-2020 period. EPA's recently promulgated fine particulate standard begins to address this public health concern and should result in both some reductions in greenhouse gas emissions along with reducing the number of deaths associated with exposure to fine particles.

- In addition to health benefits, greenhouse gas mitigation would lead to improved visibility, more and better recreational opportunities, and reduced nitrogen deposition in vulnerable water bodies (such as the Chesapeake Bay). These benefits, however, have not yet been studied as thoroughly as the health impacts cited above.

- In 1999, EPA's CCTI programs alone are expected to also reduce NOx emissions by 90,000 tons per year, improving both air and water quality.

The President's CCTI makes sense right now: it hedges our risk of climate change and puts us on the right path should the science dictate more rapid reductions would be required in the future, it saves businesses and consumers money, and it reduces other dangerous forms of pollution.

In closing, I think it's clear that the Administration is delivering on its commitment to an environmentally sound and economically sensible approach. We are closely monitoring the science to make sure that our actions are proportionate to the risks we face. Internationally, we successfully negotiated a definitively American blueprint for the global response to climate change: targets and timetables, national flexibility, market-based approaches and developing country participation The tax credits and programs in the President's Climate Change Technology Initiative will provide economic and environmental benefits right now, while stimulating early action and positioning the United States to prosper in the global market for clean technologies that will provide the solution to global warming. We look forward to continuing to work with the Congress, the private sector and the American people as we move forward. I will be happy to answer any questions that you may have.

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DAVID M. GARDINER
ASSISTANT ADMINISTRATOR
OFFICE OF POLICY, PLANNING, AND EVALUATION
U.S. ENVIRONMENTAL PROTECTION AGENCY

David M. Gardiner has served as the Assistant Administrator of EPA's Office of Policy, Planning, and Evaluation (OPPE) since June 14, 1993. Mr. Gardiner directs the Agency's analytic and policy development activities regarding climate change. Administrator Browner has also charged him with establishing EPA's new Center for Environmental Information and Statistics. In addition, Mr. Gardiner leads several of the Agency's major initiatives to reinvent environmental regulations, particularly in the areas of paperwork reduction, community-based environmental protection, economic analysis, and innovative approaches to specific industries like transportation, electric utilities, agriculture, environmental technology, and metal finishing.

Prior to joining EPA, Mr. Gardiner was the Sierra Club's Legislative Director in Washington, D.C., where he directed efforts on a broad range of environmental issues, including air, water, and waste pollution, energy, the international environment, and land protection policy.

Mr. Gardiner received his Bachelor of Arts degree in history, with honors, from Harvard University. He resides in Arlington, Virginia, with his wife and three daughters.

Chairman SENSENBRENNER. Thank you very much, Mr. Gardiner.

And the final witness for the Administration is Gary Bachula—I have it right this time?

Mr. BACHULA. You have it right.

Chairman SENSENBRENNER. The Acting Under Secretary for Technology at the Commerce Department. Please try to limit your remarks to 5 minutes so that we can get to questions and really have fun.

Mr. BACHULA. Really have fun——

TESTIMONY OF MR. GARY R. BACHULA, ACTING UNDER SECRETARY FOR TECHNOLOGY, U.S. DEPARTMENT OF COMMERCE, WASHINGTON, DC

Mr. BACHULA. Thank you, Mr. Chairman.

As Dr. Gibbons indicated, the U.S. Global Change Research Program is an important part of understanding the nature of the problem. And I would just like to point out that, at the Department of Commerce, NOAA, is a very major player in that program, both collecting data and doing the science and doing the simulations that have lead to our understanding.

But today, I want to focus on another aspect of science and technology relating to climate change, and that is to find solutions to the problem. We believe that we can pursue economic growth, higher living standards for our people, and environmental protection at the same time. We think that it is a false choice to say that we must sacrifice economic growth in order to have a clean environment. We can have both, and the key is new technologies. If you can produce the same product with less energy, with less waste, with less pollution, a company can be more productive. You can be more competitive; you can make and sell your products for less; you can make higher profits, pay higher wages, and compete better in the global marketplace.

The research that we propose to carry out at the National Institute of Standards and Technology under this Climate Change Initiative, will be good for the economy, good for industry, good for jobs—and almost as a "by the way"—good for the environment.

Let me turn to the specific new research proposals that we have under this Climate Change Technology Initiative. They fall under three areas of research, and most of this is pretty basic research—understanding and cataloguing the fundamental nature of materials, fluids, gases, and their interactions. This is what NIST does for a living, and this is exactly what an organization dedicated to measurements, standards, and testing should be doing.

The first area is membrane-based alternatives to distillation. Today, about 43 percent of the energy used by the U.S. chemical industry—which is about 9 percent of the energy used by all industry—is consumed by large-scale separations of chemicals based on distillation. You'll know what distilling is from eleventh grade chemistry—it's essentially boiling a liquid to separate out the parts. That heating process consumes a great deal of energy. It turns out that there may be a better way to separate chemicals by using membranes. The potential process would use far less energy. It actually would produce purer separations. And the predictions are that it will be done at a reduced cost. This could be a win-win for the chemical industry as well as for the rest of us.

Now, what NIST proposes to do is the most basic research into understanding the properties and nature of various membrane alternatives and we will develop a data base for all to use. We will do modeling studies of how chemicals transport through these membranes, and we will attempt to catalogue that information so that other researchers can carry forward the work in more applied fashion to develop new processes and equipment to do this kind of work.

A second category of work will relate to alternative working fluids for more energy efficient processes. Fluid systems are important for a wide variety of industrial processes, such as electric power generation, heating-cooling systems, industrial cleaning, and micro-electronics manufacturing. Many of the fluids currently used could be improved upon to either produce greater energy efficiency, or to find alternatives that have less negative impact on the environment themselves.

Let me give you one example in this category, power generation. Right now, whether we use coal, natural gas, oil, or another source to produce heat, what we do is we boil water. We boil water to create steam that turns an electrical turbine—a generator. Regardless of the source of the heat, it is the boiling of water that ultimately moves that generator. It turns out that there are promising alternatives to using just water involving different thermodynamic cycles, different fluids—particularly different mixtures. Carefully chosen mixtures of ammonia and water, for example, may improve the efficiency of coal-fired power generation by as much as 20 percent. And again, NIST's role would be the most basic. We would provide U.S. industry with the required thermo-physical property data and models needed to design and optimize processes to exploit the properties of different combinations of these fluids.

A third area of our proposed work involves biotechnology. As you know, plants remove CO_2 from the atmosphere through photosynthesis. A byproduct of photosynthesis is oxygen, so this is a very important chemical reaction for every human being. But it turns out that the enzyme that captures CO_2 in plants during photosynthesis is relatively inefficient. NIST proposes to do research that could lead to improving its efficiency by undertaking extensive characterization of the biophysical and biochemical properties of the protein in concert with protein engineering efforts to optimize it's activities. The results of this work could lead to a new generation of plants that absorb more CO_2. And while this could be an important contribution to the solution of climate change, it also could be a boon to the agro-chemical industry and for expanding opportunities for developing biomass-derived products.

Mr. Chairman, the work we propose to do is basic but it can have enormous potential impact. It is what NIST does and does best. And it will be done, as always, in our NIST laboratory efforts in close concert with industry. We believe that partnerships with industry work and that they can lead to not only major technical breakthroughs, but also to ones that are relevant to the marketplace.

At Commerce, we also chair the intergovernmental committee that oversees the Partnership for a New Generation of Vehicles (PNGV). And we operate a small secretariat in Commerce to coordinate the PNGV activities. PNGV has proven that government and industry can work together and can pursue, in parallel, both public and private goals. And it has proven—witness the concept cars unveiled in Detroit a month ago—that bold technological goals, often beyond the realm of imagination, the realm of what some think was possible, can be obtained if we work together. Our success with PNGV to date leads me to believe that we can tackle issues like climate change and do it in a way that keeps American industry competitive and ahead of the curve, keeps American workers employed, and keeps our American economy humming. With or without the Kyoto accord, these kinds of investments in new technologies make sense for America.

[Mr. Bachula's prepared statement and biography follow:]

Testimony of

Gary R. Bachula

Acting Under Secretary for Technology

Technology Administration

U.S. Department of Commerce

before the

Committee on Science

U.S. House of Representatives

on the subject of

The Department of Commerce's Current and Planned Global Climate Change Initiatives

February 12, 1998

Mr. Chairman, members of the House Science Committee, thank you for inviting me here today to talk about the Commerce Department's part in the President's climate change initiative.

Global climate change is the primary environmental challenge facing not only the United States, but the world. Building on a solid foundation of climate science, President Clinton is committed to strong and sensible action to reduce greenhouse gas emissions. A key element of the President's program is a $6.3 billion investment in tax cuts and R&D for new technologies over five years. Under the President's FY 1999 budget, the Commerce Department would receive $7 million for new climate change technology initiatives.

My remarks this morning will focus on the Commerce Department's current research efforts to alleviate the causes of global climate change, as well as proposed activities under the President's Global Climate Change Initiative.

First, however, let me begin with a few words about the Department of Commerce's National Oceanic and Atmospheric Administration (NOAA)—recognized around the world as an authority in the science of the environment—whose work is focused on gaining a better scientific understanding of the nature of climate change.

NOAA has played a key role in the development of periodic state-of-science assessments and professional literature developed by the United Nations and professional scientific bodies, such as the recently published special report, "Regional Impacts of Climate Change: An Assessment of Vulnerability," of the 1998 Intergovernmental Panel on Climate Change. NOAA also plays a key advisory role to the President and other Federal policy makers. For example, a NOAA laboratory director served as science advisor to the U.S. delegation at the December 1997 meeting at Kyoto on climate change, playing a critical role in ensuring climate change discussions were informed by objective scientific input.

NOAA programs have been monitoring, collecting data, and carefully analyzing changes in the environment for many years. One especially valuable program periodically collects air samples from some 50 locations worldwide to enable a better understanding of the global carbon cycle and its effect on climate. The station at Mauna Loa, Hawaii, has maintained the world's longest continuous record of atmospheric carbon dioxide monitoring. This information is a key benchmark for climate change studies.

The Department of Commerce, through NOAA, is also a key participant in the U.S. Global Change Research Program—a multiagency effort to improve our understanding of medium and long term climate fluctuations and climate change. NOAA's work helps ensure that objective scientific knowledge informs decision making about Federal environmental policies and programs.

The Department will be happy to provide answers to any questions you may have about NOAA's programs.

Now, before I get to a detailed discussion of the Commerce Department's programs, let me take a minute to establish the global economic and environmental context for our efforts.

Global Economic Growth, Industrialization Stressing the Environment

Mr. Chairman, globalization and the rapid advancement of technology are driving worldwide economic growth and rapid industrialization in nearly every corner of the world. However, robust economies, new jobs, and individual prosperity, are also placing increased stress on our global environment—on our lakes, streams, rivers, oceans, land, and air.

In the emerging industrial nations, economic growth is lifting millions out of poverty. In East Asia alone, the number of poor fell from 400 million in 1970 to 180 million in 1990, and China has lifted an estimated 175 million people out of poverty. These nations are preparing for further growth, expanding their road systems and establishing other infrastructure. As time goes on, standards of living will rise for more and more people and consumer demand will grow.

For example, China projects that its domestic market for automobiles will grow from 180,000 autos in 1992, to 1.5 million in 2003—an annual average growth rate of more that 66 percent. Auto sales in South Korea already reached 1.5 million in 1993, and 15 percent average annual growth is projected for several years.

And while the most rapid growth is taking place in emerging economies, growth in the United States is also having an impact on the global environment. By the end of 1993, there were 194 million registered motor vehicles in the United States. These vehicles contribute about third of our smog-related air pollution, and one-third of our carbon dioxide emissions contributing to global climate change. According to some projections, there could be nearly 270 million registered vehicles in the United States by the year 2010.

Economic Growth and Environmental Protection: Compatible Goals

For decades the public debate on economic growth and environmental protection was framed by the belief that progress in either area came at the expense of the other. In many minds, the linkage between global growth and environmental impact has seemed clear—more growth, more pollution; less growth, less pollution. Those who stood strongly for economic growth were deemed opponents of the environment, while those who stood for environmental protection were deemed opponents of progress and prosperity.

Five years ago, President Clinton brought to office a new way of thinking—a solid belief that we, as a Nation, could—and must—pursue both economic growth and environmental protection simultaneously. He recognized that a choice between a higher standard of living and a cleaner environment was a false choice—Americans want both.

And so he committed the United States to a new course, one that rejects the notion that we must choose between jobs and the environment. In *Technology for a Sustainable Future,* the President sets out the challenge before the United States and the world—sustainable development—and the path to success—an effective partnership between the public and private sector to develop and deploy technologies that will protect the environment while sustaining economic growth. This path is built on a foundation of faith in our ability to "do good" and "do well" at the same time.

Doing Good, Doing Well

We believe the record speaks for itself. During the President's five years in office, the United States has generated 14 million new jobs—over 3 million jobs in just this past year. Real GDP grew 3.8 percent for 1997 as a whole—the highest growth rate in nine years—and measures of income have been growing even faster. We have the lowest unemployment in over 24 years, with the unemployment rate below 5 percent for the last eight months. Inflation has declined to its lowest level since 1965. And this month, after years of national red ink, President Clinton has submitted a plan that not only balances the Federal budget, but includes a surplus. And, at the same time all this was accomplished, we were able to make substantial Federal investments to protect our environment, including $111 billion on natural resources and the environment, of which more than $33 billion was spent specifically on pollution control and abatement. And these figures don't even include environmental clean-up programs at the Department of Energy and Defense.

The latest figures show that as of 1996, the U.S. environmental industry employed 1.3 million Americans and has revenues of over $180 billion. The global market for environmental technologies, which stands today at about $450 billion, is expected to grow to some $600 billion by the year 2010. And as the global market grows, so do U.S. exports of environmental technology—$16 billion in 1996, a 60 percent increase since 1993.

But despite this growth, our firms still export only 8 percent of their total production, a far smaller percentage than our competitors in Europe and Japan. This untapped exporting potential represents a great opportunity for our environmental industry to grow and create more high-wage jobs for Americans.

In addition, environmental technologies contribute to the vitality of other U.S. industrial sectors by enhancing their competitiveness in the increasingly environment-sensitive international marketplace.

A Paradigm for Public-Private Partnerships to Address National Goals

Achieving economic growth and stronger environmental protection has meant building strong public-private partnerships to demonstrate the reality that economic and environmental progress can go hand-in-hand. One particular effort—the Partnership for a New Generation of Vehicles—illustrates how government and industry, working together, can accomplish goals beyond what either could achieve separately, and do it in a way that is timely, cost-efficient, and collegial.

The Partnership for a New Generation of Vehicles

Shortly after his inauguration, President Clinton and his team began considering how best to address difficult policy problems involving transportation—specifically, the environmental and energy policy problems posed by our ever-increasing reliance on the automobile. This work was also informed by a recognition of the importance of the auto industry to the U.S. economy.

Since vehicle miles traveled has increased at a rate of about 3% per year over the last decade, and consumers are favoring ever-larger and less fuel efficient vehicles, we recognized that the environmental and energy policy issues were not being addressed by the marketplace. We realized that only a truly bold research project could provide the technology to address these policy issues, and that the auto industry needed to be committed to that project in order for it to work.

After six months of discussions, President Clinton and the CEOs of the Chrysler Corp., Ford Motor Co., and General Motors Corp. announced the formation of the Partnership for a New Generation of Vehicles on September 29, 1993, an historic partnership to develop a new generation of vehicles with very low emissions and up to three times the fuel efficiency of conventional cars.

Public Policy Objectives of PNGV

PNGV advances three important public policy objectives: environmental protection, energy security, and U.S. economic competitiveness.

Environmental protection— Motor vehicles contribute about a third of the United States' human-origin greenhouse gas emissions that are contributing to global climate change. And this contribution is growing. Since carbon dioxide emissions are directly related to fuel efficiency, a three-fold improvement in fuel efficiency—a key PNGV goal—would reduce carbon dioxide emissions by two-thirds per vehicle mile traveled.

U.S. energy security— The U.S. is becoming more dependent on foreign oil with each passing year. In 1995, imports accounted for 50 percent of U.S. oil consumption. Petroleum imports make up ten percent of the Nation's import inventory and account for a large percentage of the Nation's trade deficit. With domestic consumption growing 1.1 percent a year, and domestic production falling 1.4 percent a year, the Energy Information Administration predicts that by the year 2000, imports will make up 56 percent of our consumption. By 2010, imports are expected to exceed 60 percent of domestic consumption. As the economies of the emerging nations continue to grow, so too will their demand for oil.

Fuel for ground transportation accounts for 43 percent of our petroleum-based energy demand. When we find ways to get more for each dollar spent on a barrel of oil, it helps us reduce our growing dependence on this finite resource.

U.S. competitiveness—The U.S. auto industry accounts for 4.5 percent of GDP, and one-in-seven American jobs is tied to this industry. Recently, several major foreign competitors have demonstrated advanced technologies and vehicles that significantly improve fuel efficiency and reduce emissions. In the absence of a continuing, effective PNGV program, these advances could represent a competitive challenge to our domestic automobile companies, American jobs, and the U.S. economy.

PNGV Goals

The Department of Commerce chairs the Operational Steering Group of the Partnership for a New Generation of Vehicles because of our long history of partnership with the private sector. A highly ambitious 10-year research and development program, PNGV has three goals:

1. Improve the productivity of the U.S. manufacturing base through the adoption of new technologies;

2. Pursue technology advances that can lead to improvements in fuel efficiency and reduction of emissions in current vehicle designs; and

3. Develop the technologies for new generation, mid-size family sedans that get up to 80 miles per gallon, carry up to six passengers and 200 pounds of luggage; meet or exceed current safety and emissions requirements; provide ample acceleration; are at least 80 percent recyclable; and provide range, comfort, and utility similar to today's models, and cost no more to own and operate.

Under PNGV, teams of scientists and engineers from 19 Federal government laboratories have been working with counterparts at Chrysler, Ford and GM—under their U.S. Council for Automotive Research umbrella organization—automotive suppliers, and universities. The centerpiece of the Partnership is a coordinated portfolio of hundreds of research projects underway at government, auto company, supplier, and university research facilities.

Four years into the 10-year partnership, PNGV has made solid progress toward developing the enabling technologies for affordable, midsize, family sedans capable of achieving up to 80 miles per gallon with very low emissions. Last month, at the 1998 North American International Auto Show in Detroit, Chrysler, Ford and GM unveiled advanced concepts that reflect our progress toward PNGV goals.

However, while the new concepts unveiled in Detroit are impressive, significant additional technology breakthroughs and advancements will be required to achieve the ambitious PNGV goals. Chrysler, Ford, and GM are all working on high-mileage concept vehicles to debut in 2000, to be followed by production prototypes in 2004. The government partners and their national laboratories are continuing to pursue high-risk, cooperative research and development with the auto industry to advance critical enabling technologies for possible use in these vehicles.

PNGV Benefits

Clearly, a successful PNGV program would have profound effects for the United States and the world:

- creating a healthier global environment by reducing vehicle pollution,
- improving U.S. national security by reducing our reliance on oil,
- improving the Nation's balance of trade by reducing oil imports,
- extending the life of the world's petroleum resources by using them more efficiently,
- increasing the competitiveness of the U.S. auto industry,
- opening new markets across the globe, and
- protecting existing high-wage jobs and create new ones.

These factors indicate a clear convergence of public and private interests. And it is this convergence that established the foundation for a partnership between the Federal government and U.S. automakers to work together to achieve the technological breakthroughs required to produce a new class of highly energy-efficient and environmentally-compatible vehicles.

PNGV Characteristics: A Model for Public-Private R&D Partnerships

But aside from the laudable goals and prospective outcomes of the program, PNGV stands as a model for future public-private partnerships for several other reasons:

- replaces a long-running, adversarial relationship between a U.S. industry and the Federal government, with one grounded in cooperation and partnership,

- a partnership grounded in market-based principles,
- a cost-sharing arrangement under which the Federal government funds a proportionately larger share of fundamental research, and industry funds a proportionately larger share of R&D as it moves closer to commercial viability,
- the virtual aggregation of multiple government R&D programs, under the management of several Federal agencies, to create synergy and to establish a common purpose,
- the inclusion of a broad array and multiple tiers of suppliers,
- the inclusion of multiple components of America's innovation system—industry, government, and universities,
- industry involvement in crafting an R&D agenda that spans the spectrum of R&D, from basic science to production prototypes,
- clear goals and a clear timeframe for their achievement;

And finally, my last words on the effectiveness of PNGV come from an article published this week in one of America's leading business publications—Business Week:

> "This shift [toward more fuel efficient vehicles] in Detroit's thinking can be credited substantially to the U.S. government, both through its antipollution regulations and the Administration's Partnership for a New Generation of Vehicles....
>
> "Now, at the midpoint of the 10-year effort, the alliance is paying real dividends. The progress, Detroit recently claimed [at the Detroit auto show], would not have occurred without a government policy commitment to cleaner air. Washington deftly used the CAFE standards as stick and the PNGV as a carrot....
>
> "It took substantial public research and development funding, as well as a goal that seemed far-fetched to create a serious commitment to entire new technologies....
>
> "Public regulation and public research must both play a role, or pollution will be excessive. So don't count government out. Detroit didn't."

Other Department of Commerce Climate Change-related Programs

In addition to our role in PNGV, the Commerce Department has a number of other activities currently underway to address global climate change, as well as $7 million in new initiatives proposed in the President's FY 1998 budget.

The Commerce Department's National Institute of Standards and Technology supports a wide range of activities that contribute to the Administration's efforts to understand and address global climate change. Although NIST's activities are driven primarily by economic considerations, we recognize their potential for improving the global climate. Let me illustrate how these economic and environmental goals can be complementary.

NIST Research in CFC Alternatives—A Case Study: NIST's research in support of the development of alternatives to chlorofluorocarbons—better known as CFCs—provides an excellent example of how a modest Federal investment in R&D can yield substantial environmental and economic benefits for the nation.

Until the past decade, most refrigerants used throughout the world were made up of CFCs due to their desirable physical and economic properties. However, research showing the detrimental effects of CFCs on the Earth's ozone layer—which provides protection from the sun's harmful rays—resulted in an international accord in 1987 to phase out production and consumption of CFCs, and to replace them with other, more environmentally-friendly compounds.

NIST helped industry cope with this fast changing regulatory environment by identifying the basic requirements for new refrigerants, then started research to determine the physical properties of such candidates. The results of these efforts were made available to industry. NIST's most effective work came in the form of a computer program—REFROP, available to the public through NIST's Standard Reference Data Program—that enables manufacturers and users of refrigerants to model the behavior of alternative refrigerants.

NIST data and REFROP provided a standard that enabled industry to make important decisions. Without these standards, each company would have had to develop their own—incurring time-consuming delays and millions of dollars in costs. And in the end, each company probably would have made different choices about refrigerants, a scenario that would lead to a technical "Tower of Babel" for the maintenance and repair community and a nightmare for consumers.

An analysis of the economic benefits of NIST's alternative refrigerants research program showed an extremely high internal rate of return and a benefit-to-cost ratio of almost 4-to-1. And this analysis does not include the incalculable benefits that result from protecting our planet's ozone layer.

Manufacturing Extension Partnership (MEP) Program: Our Manufacturing Extension Partnership is a promising mechanism for helping the Nation's smaller manufacturers reduce or eliminate pollution in their operations, and we are integrating environmental technical assistance into the broader array of services provided by MEP centers. For example, through these environmental services, manufacturers can receive advice and direction to reduce their dependence on fossil fuels and their use of ozone depleting substances.

The President is requesting $1 million to add to these services a strong focus on the transfer and diffusion of climate change technologies. In addition, MEP centers plan to build upon our existing relationship with the Department of Energy's Industrial Assessment Centers which focus on energy efficiency. We envision a two-tiered program for promoting the use of such technologies among smaller manufacturers. In the near term, we will promote the dissemination and diffusion of existing off-the-shelf and state-of-the-market technologies. In the longer-term, advanced technologies developed by NIST would be introduced to more sophisticated companies, or as major capital improvements and replacements to energy-intensive systems become necessary. Today, eight percent of NIST interactions with manufacturers in the MEP program focus on environmental issues. By the year 2000, the MEP is expected to reach approximately 36,000 manufacturers annually, establishing promising channels for the dissemination and diffusion of climate change technologies.

Advanced Technology Program (ATP): The Advanced Technology Program encourages high-risk research on enabling technologies which have strong potential for economic benefit to the Nation. ATP does not have a focused program in global climate change, although it does have a strong portfolio of promising research that could generate significant improvements in energy efficiency and the global climate. ATP has invested $90 million in about 60 projects that address five broad categories of environmental technology development: pollution prevention, clean and efficient engines, clean energy, energy use and management, light-weight automotive materials, and renewables and recycling projects.

The bridge to a sustainable future will be built with lots of contributions that address our environmental challenge from many different angles. Accordingly, our ATP portfolio of projects holds the potential for lots of individual contributions that could add up to a significant benefit for the environment and our economy.

Partnership for Advancing Technology in Housing: Buildings produce 35 percent of U.S. greenhouse gas emissions. For example, the energy used in the typical home causes more greenhouse gas emissions than does a typical car. New technologies offer us an opportunity to reduce energy demand and emissions, while holding the line on housing costs.

The Administration's Partnership for Advancing Technology in Housing (PATH), led by the Department of Housing and Urban Development, brings together a number of government agencies and industry to develop, demonstrate, and deploy housing technologies, designs, and practices that can significantly improve the quality of housing without raising the cost of construction. A number of PATH goals address climate change and environmental issues. These include targets for reducing carbon emissions, water use, and construction materials; increasing the use of recycled materials; and improving indoor air quality. PATH also seeks to identify and remove barriers that have reduced incentives for innovation in housing design and construction. NIST is supporting numerous R&D activities that can contribute to PATH goals, and will play a key leadership role in the initiative.

New NIST Climate Change Initiatives

Finally, the President is requesting $6 million to improve the measurements and data underpinning the next generation of climate change technologies that will reduce greenhouse gas emissions and produce more efficient industrial processes. Enormous amounts of energy are consumed, with concomitant greenhouse gas emissions, in many areas of industrial manufacturing and power generation. We know technology holds the potential to enable significant improvements. For example, from 1970-1996, the energy required to produce each dollar of GDP dropped 32 percent as a result of improved technologies and conservation.

We propose to invest in developing the measurements and data that will help enable large-scale carbon dioxide removal from the atmosphere, industrial reductions of carbon dioxide emissions, and replacement of industrially important ozone-damaging gases with environmentally acceptable and better performing alternatives. These investments would focus on three key areas.

Biotechnology for Increased CO2 Consumption: First, NIST would undertake research in biotechnology to provide data on structure-function relationships that could be used to enhance biomass production and to manipulate metabolic pathways for increased carbon dioxide consumption. For example, the enzyme that captures carbon dioxide during photosynthesis is relatively inefficient; it's activity can be enhanced using extensive characterization of its biochemical properties and genetic engineering. Methods for integrating the optimized enzyme into plants and microorganisms will be developed for enhanced biomass production. This approach offers the opportunity not only to significantly reduce the carbon dioxide in the air, but also offers economic benefits to the agrochemical industry through improved crop yields. This effort will be made in coordination with related research at the U.S. Department of Agriculture.

Membrane-based Alternatives to Distillation: Our second area of focus is membrane-based alternatives to distillation. Large-scale separations based on distillation--the process by which different components in chemicals are separated--consume an estimated 43 percent of the primary energy used by the U.S. chemical process industry annually, and 9 percent of the energy used by U.S. industry as a whole. Membrane-based separations have much lower energy requirements than distillation processes, and offer vast improvements over other chemical separation processes in the trade-off between purity and productivity. As the U.S. chemical process industry moves to cut greenhouse gases, its needs for measurements and data on the performance characteristics of membranes will grow accordingly. To help encourage the development and adoption of membrane-based separation processes, NIST proposes to develop a membrane technology database, conduct experimental and modeling studies of transport in membrane materials, and produce characterization techniques useful to both developers and end-users of membrane technology.

Alternative Working Fluids for Energy-efficient Processes: Our third area of focus for measurements and standards for climate change involves alternative working fluids for energy-efficient processes and reduced global warming effects. Fluid systems are pervasive in many important industrial processes such as electrical power generation, heating and cooling systems, industrial cleaning, and microelectronics manufacture. Often these fluids have significant global warming effects. In other cases, the use of a fluid in a particular application wastes energy because the fluid or fluid systems are not the best for the task at hand. In these cases, the process indirectly produces additional carbon dioxide in proportion to its inefficiency, thus contributing to global warming. Our goal is to address the measurements and data needed to develop energy-efficient and environmentally-acceptable alternative working fluids in several applications. These include power generation systems, next generation refrigerants and insulating gases, cleaning fluids in the semiconductor industry, and industrial-scale use of carbon dioxide to replace harmful organic solvents used in chemical processing.

Power generation provides a good example of what we hope to enable. The United States relies almost entirely on water steam to transfer energy from a primary energy source to the rotation of a turbine, and then to electricity, with the primary energy usually coming from fossil fuels that release carbon dioxide. Alternatives to this approach, involving different thermodynamic cycles and working fluids, may provide significant potential for reducing carbon dioxide emissions. For example, if we could replace that water with an ammonia and water mix, we may be able to reduce coal consumption by 20 percent in coal-fired applications. Such a system may also make geothermal energy production competitive and an entirely non-polluting source of power. NIST's role would be to provide U.S. industry with the thermophysical property data and models needed to advance such technology.

In the Advanced Technology Program, the Manufacturing Extension Partnership program, and the Measurements and Standards program, NIST has the staff expertise, experience, and industry partnerships to contribute to technology-driven economic growth and, at the same time, helps us reach our Nation's environmental goals.

Conclusion

In conclusion, let me ask you to examine the programs I have discussed today in the context of broad national policy objectives that I think we can all agree upon:

- a strong U.S. competitive position across a broad array of industries,
- a growing standard of living for all Americans,
- less reliance on foreign sources of oil, and
- a cleaner environment for ourselves, for our children, and for generations of Americans to come.

Throughout our Nation's history we have made investments in research and development to meet critical national needs: to provide for the nation's defense, to ensure an adequate supply of food, to protect our health, and to ensure our safety. The linkage between sustained Federal R&D investments to meet these needs and U.S. global leadership in key industries—agriculture, aerospace, satellites, computing and communications, and biotechnology—is clear.

In the same way, we must commit our Nation to the development of environmental technologies to ensure U.S. global leadership in an industry that is so closely tied to the vitality of our economy, the health of our people, and the future of our children.

These programs make sense for America.

U.S. Dept. of Commerce
Technology Administration

GARY R. BACHULA

DEPUTY UNDER SECRETARY FOR TECHNOLOGY

Dr. Mary L. Good resigned as Under Secretary for Technology effective June 3, 1997. Gary R. Bachula (Deputy Under Secretary) is currently the Acting Under Secretary for Technology.

Gary Bachula is the Deputy Under Secretary for Technology at the U.S. Department of Commerce's Technology Administration. As Deputy to Dr. Mary L. Good, the Under Secretary for Technology, Bachula helps to oversee the work of the Office of Technology Policy, the National Institute of Standards and Technology, and the National Technical Information Service.

The Office of the Under Secretary also provides advice and assistance to the Secretary of Commerce for the formulation of new policies and program initiatives for science and technology policy matters. In this capacity, the Technology Administration assists in the development and promotion of Federal technology policies to increase U.S. commercial and industrial innovation, productivity, and economic growth.

Bachula serves as the Department of Commerce representative to the Committee on Education and Training of the National Science and Technology Council.

With both a B.A. in economics and a law degree (J.D.) from Harvard, Bachula served as Chief of Staff to U.S. Rep. Bob Traxler of Michigan from 1974 to 1986, where he advised the Congressman on appropriations for NASA, EPA, the National Science Foundation, and other federal agencies.

From 1986 to 1990 he worked for Michigan Governor James J. Blanchard, serving as Chairman of the Governor's Cabinet Council. The focus of the Cabinet Council was to "reinvent" Michigan's job training and education programs.

Bachula also served as Vice President for Planning and Program Development for CIESIN, the Consortium for International Earth Science Information Network. CIESIN is federally-funded project to intergrate and extend the value of current and future U.S. enviornmental data collection efforts (satellite and on the ground) to a broad array of applied users.

A native of Saginaw, Michigan, Bachula is a 1964 graduate of Saginaw High School, was named Saginaw High's Distinguished Alumnus in 1990. He served at the Pentagon in the U.S. Army during the Vietnam war.

Chairman SENSENBRENNER. Thank you very much.

Just as a procedural note, we'll be voting in 50 to 55 minutes on the resolution dismissing the challenge of Congresswoman Sanchez's election. I would like to wrap this hearing up so that Members will not have to come back and the witnesses and the audience can go on their separate ways. So I'm going to be kind of ruthless in enforcing the 5-minute rule. So I will yield myself 5 minutes.

RELATIONSHIP OF SENATE RATIFICATION OF THE KYOTO PROTOCOL TO THE FY 1999 BUDGET SUBMISSION

Chairman SENSENBRENNER. The testimony we have heard from the Administration witnesses today, to me operates under the assumption that the Administration is operating under the Kyoto Protocol even though it has not been signed by the President and not been submitted to the Senate for ratification. If the Kyoto Protocol does not get ratified by the Senate at some time in the future, how much of this budget submission would not be present today?

Dr. GIBBONS. I don't think much would be missing at all, Mr. Chairman. Everything that the Administration proposes to do is—reflects our concern that we're facing a global environmental challenge for which the United States is responsible for about 20 percent of the whole global contributions. The program the President has outlined, as you heard from the witnesses today, makes sense for a variety of reasons. They attack the fundamental issues of continuing to grow our economy to innovate with new technology and to become more resource efficient in the process. It's preparing for the kind of 21st Century economy that we feel is going to be important. The federal role is minor. It attempts to catalyze and partner with the private sector in these ventures, so I dare say that it would have very little change.

DEPENDENCE OF BUDGET INITIATIVES ON PROPOSED TOBACCO SETTLEMENT

Chairman SENSENBRENNER. Much of the new spending initiatives the Administration contains in the budget in this area and in other areas seem to be predicated on a tobacco industry settlement being approved by the Congress. I sit on the Judiciary Committee, and let me say that at least the immunity parts of the tobacco industry settlement are in deep, deep trouble over there. What happens if Congress does not approve the tobacco settlement in a manner that is agreeable to all parties, particularly the tobacco companies who are going to pay for a considerable part of this? Do we have to drop a lot of the initiatives that you have proposed off? Should that happen in Congress on the tobacco settlement?

Dr. GIBBONS. I should certainly hope not, Mr. Chairman. The President's budget has offsets specifically identified for all of the expenditures so that we are containing ourselves within the cap as agreed upon. There is an anticipation of some revenues from a tobacco settlement; that's not in question. The question is it really relates to the Congress' decision about how to fund the budget. We have made a proposal which includes certain assumptions including a modest projection of income from some tobacco settlement. The President's plan for, for example, global climate change is a spending plan, and if the Congress wants to provide funding it with some other mix of resources, that's the Congress' responsibility. We propose——

Chairman SENSENBRENNER. Or how about not spending the money at all, because we aren't going to get the money from the tobacco companies if the settlement is rejected by Congress?

Dr. GIBBONS. If the tobacco money doesn't come in or other sources or revenue do not appear, then Congress and the Administration have to be concerned. But we do cut out—my point is that——

Chairman SENSENBRENNER. Dr. Gibbons, I guess what I'm hearing from you is that we've kind of got a club over our head that we're going to have to approve a tobacco settlement in order to do all of these nice things, and if Congress should not approve a tobacco settlement for a whole host of reasons, then our goal in achieving a balanced budget is either down the drain or we're going to have to take the heat for the Government not being able to fulfill the promises that are contained in this budget. Now, when are you guys and ladies going to quit making Congress into the bad guys and girls on this and start working in a partnership?

Dr. GIBBONS. Mr. Chairman, as I think you know, I've been pretty much an advocate of partnering for a long time. I think that's an unfair cut.

Chairman SENSENBRENNER. Well, from what you've been answering these questions, I think you've been slipping from what your previous——

Dr. GIBBONS. Well, let me answer your question, if I might; if I have to repeat myself. We proposed a budget which includes a substantial increase in our research and development as one of our investments for the 21st Century. Along with that are identified sources of revenue so that we have a balanced budget for Fiscal Year 1999. If Congress chooses to balance that budget in some other way for 1999, that's an important role for Congress to play, but we still stand by our proposal for expenses which include this important change in the research and development budget which is considerably less than you and others have spoken about, and we support—if Congress can come forward with an even greater increase in the research and development, we'd be delighted to work with you.

Chairman SENSENBRENNER. Well, Dr. Gibbons, I can assure you that when Congress comes forward with increases in the research and development budget, it will be funded by real money not by illusory money. My time has expired. The gentleman from California, Mr. Brown.

Mr. BROWN of California. Thank you, Mr. Chairman. I want to apologize to the witnesses that I'm going to have to be leaving very shortly, and before I leave I want to announce that our senior staff member on this Committee, Dr. Smith, will be leaving at the end of this month, and this may be his last hearing, and I want to acknowledge the great contribution that he's made over the years. Dr. Smith.

[Applause.]

Mr. BROWN of California. And, now, if I may, Mr. Chairman, I'm going to yield the balance of my time to Mr. Gordon, the next Ranking Member of the Committee.

Chairman SENSENBRENNER. The gentleman from Tennessee is recognized.

DIFFERENCES BETWEEN CLIMATE CHANGE TECHNOLOGY INITIATIVE AND CLIMATE CHANGE ACTION PLAN

Mr. GORDON. Thank you, Mr. Chairman. Dr. Gibbons, I think you are Dr. Gibbons, thanks for coming and joining us today, and I really want to reflect on some of the lessons good and bad from the past. How does the Climate Change Technology Initiative differ from the Climate Change Action Plan? What have you learned from it? You know, what have been the good things? What have been bad—not bad but not successful? And have you integrated those into the new plan? So much of what we hear are horror stories on this is going to happen; that's going to happen or great things are going to happen if we do this or that? Can we reflect, you know, maybe on some reality; what we've seen from the past rather than just wild accusations, maybe, from each side?

Dr. GIBBONS. Well, we do have a lot to learn from the past, and I think one thing we learned is that it's so easy to exaggerate the results of actions taken. I think our work on the Clean Air Act and the implementation which followed and used offsets and trading enabled us to improve our air quality at about maybe 10 percent of some of the original costs. I think some of these latter day sky is falling accusations about the cost of action on climate change are literally that, and I think past experience shows us that.

Now, it's an evolving process. What the Climate Action program that we are proposing with a combination of tax incentives and an important research and development plan directly reflects our feeling about the appropriate federal role in beginning to move us in the direction that we're all aiming at early in the 21st Century. I think the $6.3 billion mix of tax incentives and R&D is a judicious mix. I think we should watch it carefully together over the intervening years to see what works best and what doesn't work very well. So, a continuing evaluation is important, but I believe based on our earlier experiences over the last 20 years that the sky, indeed, is not falling; that we can do remarkable things if we take enough time and are thoughtful about it.

IMPACT OF IMPROVED AUTOMOTIVE TECHNOLOGY ON EMISSIONS

Mr. GORDON. I guess one last question: So much of the emissions are from automobiles—and I'm sure you could tell us what that is—and we are continuing to see announcements from the automobile manufacturers where they're maybe not going to complete clean cars but make dramatic improvements, and all of this really has come, I think, after initial projections. How is this going to affect the emissions?

Dr. GIBBONS. Well, the actions taken, for example, the cooperative work between the Federal Government and the automobile industry and its suppliers, is a good example of how if you set an ambitious goal but give it enough time and attention over time—here, we're 5 years into a 10 year program—you find that there are remarkable things that can happen, and the news over these past several months at our halfway point of our work with the automobile industry give us an enormous excitement about what advances in science and the technology that can emerge can do, and this will affect not only our whole transportation system—things such as hybrid vehicles and fuel sales—but it will also, I feel, dramatically affect the way we produce electricity, for example. It will have ubiquitous impacts on our economy.

So, I do feel very optimistic—and, of course, I come out of science, but I am constantly reminded of what high challenges can do in that community of science and engineering in terms of innovation and lower cost ways of getting to our goals.

Mr. GORDON. Thank you, Dr. Gibbons. If there's any time left, I'd like for anyone else on the panel that might have any kind of thoughts on how these new announcements by the automobiles manufacturers might impact earlier estimates of mitigation.

Dr. MONIZ. Okay, I'll make one comment from the Department's perspective. Certainly, as Dr. Gibbons noted, the halfway point of the program has helped stimulate these very interesting proposals from Detroit, but I would just add with introduction of models—certainly much earlier than expected—but I want to add that there still is a need for this very strong technology program to reach the full goal plan for 2004. Just as one example, research on fuel cell stacks will be proposed which will be a major push towards the 80-mile per hour cost effective car.

Chairman SENSENBRENNER. The gentleman's time has expired. The gentleman from New York, Mr. Boehlert.

Mr. BOEHLERT. Thank you very much, Mr. Chairman, and let me say at the outset that I agree with your expressed concern that the budget is sort of built like a house of cards, and a large share of that is dependent upon the tobacco settlement which we all know is very controversial, and that concerns me, and I want to deal with real money, because I think the programs being advanced here represent exciting initiatives and some promise for the future, and it's up to us to find that real money and not the illusionary money that the Chairman referred to.

PROMOTION OF ALTERNATIVE VEHICLES

Mr. BOEHLERT. Let me get to some specifics, particularly for Dr. Moniz. I'm especially interested in encouraging the development of a market in alternative vehicles, particularly electric and hybrid electric, both for mass transit and individual use. To what extent will your initiatives promote these technologies, for openers? And to what extent do you expect the market for these vehicles to develop over the next several years? Let's take them one at a time.

Dr. MONIZ. May I make a prologue on your opening, Congressman Boehlert, just to note that, at least in my understanding—I'm far from an expert in this—that the projections in the budget would be a nearly $10 billion surplus with the tobacco tax, and if the settlements are not in place, there would still be a surplus, so I think the prioritization is still there, but there still would be a budget surplus in my understanding.

With regard to the PNGV, indeed, in the budget there is a request for an increase of $50 million across multiple agencies, and that is precisely to advance a set of new technology initiatives. I mention, for example, this critical issue in terms of reducing costs in the fuel cell stack. Having said that, however, I'd also like to add that that is following a down select in terms of learning over 5 years and narrowing technology options with the Big 3 partners. So, it's a disciplined process pursuing the important R&D on the most important questions.

With regard to the market penetration, if you permit, perhaps, Gary Bachula from Commerce might be better suited to answer that question.

Mr. BOEHLERT. Fine.

Dr. MONIZ. Thank you.

Mr. BACHULA. Sir, the Partnership for a New Generation of Vehicles project is designed to produce three production prototype automobiles by the Year 2004 that, essentially, are sort of like your standard Taurus or Concord or Lumina; 6 passengers; 0 to 60 in 12 seconds; trunk space; it's a car like you're familiar with, but we'd get 80 miles per gallon. Now, if it gets 80 miles per gallon, that means it's going to reduce greenhouse gas emissions by two-thirds. It will be making a significant contribution to solving this overall problem. Transportation counts for about a third of the greenhouse gases put into the atmosphere; automobiles are, perhaps, about half of that. But we believe that this partnership which is aiming towards hybrid vehicles, fuel cells, technologies that are extremely advanced is already making a major contribution to this and can.

Now, what the Administration has proposed in this new budget is to add tax incentives, tax cuts, essentially, to people who would buy these kinds of new cars.

Mr. BOEHLERT. All right, before we get to that, let me—you mentioned multiple agencies. Where is the coordination coming from?

Mr. BACHULA. This is a partnership. It is a partnership between the Big Three, suppliers and a number of universities and so, and 5 federal agencies, 19 separate federal labs. We coordinate the effort in a secretariat in the Department of Commerce, but we work very closely with EPA; with the Department of Energy; with the National Science Foundation. We have a mechanism that is working extremely well.

Mr. BOEHLERT. Good, but what so often happens is that people out there across America are perplexed—you know, you hear about multiple agencies and crossing over several departments, but the coordinating agency is Commerce?

Mr. BACHULA. We manage the secretariat and chair the interagency committee, but this is very much a partnership, and the Department of Energy has the largest part.

Mr. BOEHLERT. You've convinced me that it's a partnership, and I'm very happy about that, but if I want to go direct questions to one specific source, that source would be Commerce?

Mr. BACHULA. Send them to me and we'll answer them.

[Laughter.]

EFFECTIVENESS OF TAX CREDITS

Mr. BOEHLERT. Okay, fine. Now, you mentioned the tax credits. How effective have tax credits been in the past in inducing the use of innovative technologies? What experience do we have to point to with, hopefully, pride?

Mr. BACHULA. Obviously, the tax credit will be a value if the price to the consumer minus the tax credit is attractive in terms of the alternatives, and right now, for example, with these advanced cars we're skating towards where we think the hockey puck will be. There aren't cars that meet these standards right now that can be produced for this price, but at the rate of improvement that is taking place in the design and in the research, we believe they will be there early in the next century.

POTENTIAL OF HYBRID AND ELECTRIC VEHICLES

Mr. BOEHLERT. All right. Finally, the last question—my time is up; I know it, and before the Chairman gavels me—as an inducement to more people getting into R&D in this business—hold that gavel up——

[Laughter.]

Mr. BOEHLERT. What's your forecast as to the look to the future? I mean, are we investing wisely if we can, for example, increase the range which is a real problem with the hybrid and the electric vehicles? As you look ahead to the market potential, do you see it there? Is it something that's real?

Mr. BACHULA. The goal of this car is to be very much like a car that most consumers are familiar with except under the hood it's going to be dramatically different. It's going to cost about the same; it's going to be comfortable; it's six passengers. This is a car that looks like today's car but operates very, very differently and would be priced comparatively. If we can do all that—and we don't yet know how to do all of that—but if we can do all of that, yes, I think people will buy them.

Chairman SENSENBRENNER. The gentleman's time has expired. The gentlewoman from Michigan, Ms. Rivers.

Mr. BOEHLERT. I was going to yield back the balance of my time, Mr. Chairman.

[Laughter.]

Chairman SENSENBRENNER. Well, you're currently in the hole like the budget is, so it's——

[Laughter.]

Chairman SENSENBRENNER. The gentlewoman from Michigan.

COMPARISON OF U.S. AND FOREIGN INCENTIVES FOR AUTOMOBILES

Ms. RIVERS. Thank you, Mr. Chairman. A previous speaker mentioned that this debate should be centered around real money, and I agree, but the real money I'm concerned about are the paychecks that go to the hundred thousand plus constituents in my district who make automobiles, and I was very dismayed last night to turn on, I believe it was NBC, and see a very interesting story on Toyota's Prius car which they are moving ahead very quickly with. It comes as close to a perpetual machine than anything I've seen developed, and it's a very frightening thing for somebody who represents a district where making automobiles is what we do and what we do very well.

I'm also very distressed when I see New Technology Week saying Japan carmakers are—have a 10-year head start over Detroit, and it certainly seems to me that the way people, like my constituents, are going to be protected and are going to be able to maintain their quality of life is to get ahead of this game technologically. So, one of the things I would like to know about is—and I would put this to Mr. Bachula and to Dr. Moniz but others may speak to it—I would like to know in terms of private, public partnerships, tax incentives, governmental activities in general, how the United States compares to our worldwide competitors? How are we doing in terms of advancing this technology through a partnership here in the United States relative to Japan to any of the other countries where they are competing with us, because I'm concerned. This was not a happy story for me to see on TV last night. Mr. Bachula?

Mr. BACHULA. Ms. Rivers, the story which you saw on CBS last night has part two and that's tonight, and that's going to tell you what the big three are doing here in this country.

Ms. RIVERS. Good. I look forward to it.

Mr. BACHULA. And that story, I think, is going to be a good one and an exciting to you and your constituents. The Partnership for a New Generation of Vehicles was announced in September of 1993 by President Clinton, Vice President Gore, and the CEOs of the big three. It was about 3 months later, according to Time Magazine, that Toyota ordered its research team to start developing what we now know as the Prius.

So, it was the American partnership in the research program that sort of generated this international competition. Now, it's coming back to us, and I think it will probably spur even faster movement than we had originally predicted to bringing these cars to market.

Other nations are very competitive with us, but they are not ahead of us in advanced technologies. The research that has gone on that we're aware of; that we know of, and some, of course, is proprietary, is going to produce a car that is very unlike your father's Oldsmobile, but it is going to look and feel and be as comfortable; it's going to be as safe; it's going to be clean; it's going to accelerate 0 to 60 in 12 seconds; it's going to have luggage room, but underneath that hood you're going to have new lightweight materials, hybrid engines, power electronics, and a lot of really neat technologies that were started in Energy Department labs and the big three are now using to make cars.

Ms. RIVERS. And I appreciate all of that. My question, though, really is around as—our role here is in government—as a government, are we giving our manufacturers and our workers the same sort of help that our competitors are giving theirs? That's really my question. Or are we, for whatever reason, saying our competitors are getting all this help, but we're not going to do it? Are we keeping up in terms of the help that we're offering our industry with what our competitors are offering theirs?

Mr. BACHULA. I believe we are. Now, it is possible—there is some evidence that the Prius which is on the road in Japan right now is getting a subsidy. It cost them about $36,000 to make them, and they're selling it for $17,000. One possible way to compete with them is just buy them all.

[Laughter.]

Chairman SENSENBRENNER. All those in favor of authorizing funds for this purpose will say aye.

[Laughter.]

Ms. RIVERS. Before I hear from Dr. Moniz I have to comment that there was a certain irony to me to find out that the engineer in charge of the Prius project was formerly from GM and was hired by Toyota to do this work. Dr. Moniz?

Dr. MONIZ. Well, I don't have too much to add to Gary's statement. I was going to note that there was a very large subsidy in the Prius, and I would not characterize their development as being ahead of ours technically. I believe we are supplying the right kind of help through partnership with our companies. It may be different in form than the Japanese system, but we are emphasizing partnership, essentially, industry consortium. We are trying to emphasize the competitive kinds of technology developments as reflected in the rather different announcements made by our big three in the last auto show. But I think it's aggressive. I would also add that the fact that the demand for the Prius has sort of been twice that expected by Toyota indicates the desire, I think, for the consumers to have this kind of product. In fact, it reminds me of a statement made in different context by John Brown, the CEO of British Petroleum. He stated that the people want, in this case, energy at a good price. They also want to protect the environment, and a good businessman knows to give customers what he wants.

Chairman SENSENBRENNER. The gentlewoman's time has expired.

Ms. RIVERS. Thank you, Mr. Chairman.

Chairman SENSENBRENNER. The gentleman from Pennsylvania, Mr. English.

EFFICIENCY OF TAX PROPOSALS

Mr. ENGLISH. Thank you, Mr. Chairman, and I'd like to welcome the panel. I've been reviewing your testimony, and I'm intrigued by a couple of things. The proposal that the Administration is putting before this Committee seems to be an odd collection of things a group of interesting research proposals and a dog's breakfast of tax initiatives which representing the Ways and Means Committee. I'm not sure that there's much to be said for them from the standpoint of tax simplification, but I'd like to dig into them a little bit.

Dr. Gibbons, have you worked with the Treasury at all to assess the efficiency of the tax proposals that are being offered here?

Dr. GIBBONS. They were developed at the Treasury Department. I'm not an economist, sir.

EXISTING TAX INCENTIVES FOR WIND AND BIOMASS

Mr. ENGLISH. I thought I saw their fingerprints on them. Do you have a sense—I guess, can you comment on whether you feel the existing tax program for wind technology and biomass has been an efficient use of our tax preferences?

Dr. GIBBONS. I think time will tell. I am pleased to observe, though, that, for instance, wind technology has moved extraordinarily over these past half dozen years. It is now at the edge of direct competitiveness, head on for generation and well ahead of that. It has a market advantage in many areas of the world now and wind technology and that industry is rapidly growing on account of that. Now, that came about through a number of years of steady advances in the technologies of blade design; of turbines; of electrical power controls, and the like. So, I think this is a good example of where these technologies—if you give them sustained support with public monies flowing in where the private sector hurdle rate is not met but the public good is out there, then you can find that combination of public and private investment really paying off for both sectors.

Mr. ENGLISH. And I think PURPA has also played in it, but I'm——

Dr. GIBBONS. PURPA did, indeed, you're right.

EXTENSION OF ETHANOL TAX CREDIT

Mr. ENGLISH. I would think a good deal more than the tax program, but I'd be curious to get an analysis of that. I notice that an extension of the ethanol credit was not included in the Administration proposal and was not part of the Administration budget. Is there any significance to that?

Dr. GIBBONS. I—David, would you want to respond to that?

Mr. GARDINER. Well, I would just say that the—in working with the Treasury Department when we had not only the Treasury experts but the experts in the Administration that worked on climate change that what we were looking for was the most cost-effective investment of those tax credit dollars and——

Mr. ENGLISH. You didn't feel that ethanol met that standard?

Mr. GARDINER. That's correct and that the—I would just say that the effort is to target the tax credits at those sectors of the economy that have the biggest impact on greenhouse gas emissions. So, that's why we're targeting transportation; that's why we're targeting industry; that's why we're targeting the building sector which is—each of——

Mr. ENGLISH. That's very interesting, because I know up until to this point the Administration had been supportive of the ethanol program and that's big news.

PROMOTION OF CARBON SINKS

Mr. ENGLISH. Let me shift in a similar direction. I notice one of the things that no one has included is the idea of using tax preferences or forestry policies to promote carbon sinks which I think is one of the more interesting ideas. Has the Administration explored this option?

Dr. GIBBONS. Yes, in fact, it was most recently visited, as you know, at Kyoto where carbon sinks became an important part of the outcome of the Kyoto agreements. It hasn't been worked out exactly yet in terms of implementation, but we do feel that the sequestration of carbon forest practices is a very important opportunity especially over periods of decades to, perhaps, a century. In the long term, of course, trees decay unless you happen to be the roof beam of a Japanese temple that lasts 600 years. Trees cycle carbon, rather than permanently store it, but I think we will be very actively engaged in trying to encourage a rational way of monitoring the dynamics of carbon as it is stored in forests and a fair way of accounting this as we measure our progress and the progress of other countries. So, it was emphasized at Kyoto, and there will be additional meetings concerning exactly how we inventory and monitor this.

Mr. GARDINER. Congressman, if I could just note, also, that the Climate Change Technology Initiative that the President has proposed included a $10 million initiative at the Department of Agriculture specifically for the purpose of looking at trees and soils and the related sinks question as well as additional funding at EPA. Dr. Moniz might also want to comment that the Department of Energy has a substantial increase in its funding for bio-fuels which we think represent a very significant opportunity to reduce greenhouse emissions.

Chairman SENSENBRENNER. The gentleman's time has expired.

Mr. ENGLISH. Thank you, Mr. Chairman.

Chairman SENSENBRENNER. The gentleman from Pennsylvania, Mr. Doyle.

PRIORITY OF FOSSIL FUEL R&D

Mr. DOYLE. Thank you, Mr. Chairman. I want maybe to just shift the discussion a little bit on to the power generating side. They talked about some of the concerns I have on meeting our energy needs and under the Kyoto Protocol. We have a lot of coal-powered utilities, electric utilities, and, as you know, we're going through this deregulation process, and one of the concerns that a lot of us have is that a lot of companies that use coal as their power source are going to see it becoming more profitable not to become generating companies anymore but get into the transmission end of the business. We've heard talk of natural gas, maybe, filling that void; that there would be an increase in the use of natural gas to meet that need, yet, one wonders how it would be economically practical and in what time frame could we build some of the infrastructure that would have to be built to accommodate this increase in the use of natural gas.

And then I look at the proposal with nuclear. When we look at the nuclear option which emits no CO_2, it doesn't seem that we're being very aggressive. We see that there's two modest initiatives aimed at sustaining nuclear energy as a viable option but really nothing on a larger scale to say Okay, for our future energy needs, let's look to nuclear as other countries; as Europe and other parts of the world have done.

It seems to me that everybody agrees that fossil fuels are still going to be very much in the picture in the foreseeable future, and while I see the Secretary in his budget announcement said we're going to see increases in research and development on fossil energy. That these initiatives will help us make better use of these resources. The numbers don't seem to indicate the kind of commitment that I would hope to see in fossil research and development.

Carbon sequestration; we're talking about spending in basic research $9 million; in the carbon sequestration R&D, $10 million. To me, the numbers seem low. What is the priority that this Administration is placing on fossil fuel research in Fiscal Year 1999, and more importantly too, what fossil fuel R&D programs were not included in this year's budget request?

Dr. GIBBONS. Congressman, I'd like to start out on that and then turn it over to Dr. Moniz. We're very much concerned and interested in what's going to happen with electricity deregulation as you are. Clearly, fossil fuels will dominate as they do now. Clearly, there is a very important future role for coal. Changes in the electricity industry generally take a half a century for major changes to roll through. That's why time is so important here to pace ourselves through various transitions. We are hopeful that some really smart ideas will emerge about the capturing of carbon, whether you could turn it into hydrogen and leave the carbon in the ground or other things. It's, in essence, a fishing trip at this point, because it's never been that seriously look at before. So, this is a very serious research effort, and as we find things that have promise, then we'll want to put more resources behind them. We certainly want to preserve the nuclear options, and we hope we will be able to determine in the coming years why it is that nuclear has become expensive, what it takes to resolve the remaining issues in nuclear, but also how to assure that we don't suddenly find ourselves with 20 percent of our electricity which is now produced without CO_2 emissions, namely from nuclear plants. If those plants go offline and you switch over to coal-fired plants, we're going to exacerbate the problem. So, we're very much concerned about rates of these plants and whether their lives might be extended.

So, we're paying a lot of attention to these fuels, and if you think—we have a concern about the U.S. situation on fossil fuels. If you look at China and their dependence on coal, it even is greater, so basic coal technologies that enable us to burn it more efficiently and with less carbon emissions are not only going to be important for our future, but also as an export technology force to the rest of the world.

AGENCY LEAD ON CARBON SEQUESTRATION

Mr. DOYLE. Well, who's taking the lead on CO_2 sequestration? What agency is taking the lead on that, and I understand you say, well, you point more money in it once you find—it just seems to me the money in it initially is very inadequate.

Dr. GIBBONS. That's a good chance for me to turn it over to the agency that is leading this, Dr. Moniz, the Department of Energy.

Chairman SENSENBRENNER. Dr. Moniz, could you please answer briefly, because we have 4 witnesses left and about 20 minutes before members of the Committee left.

Dr. MONIZ. The question had three parts—I'll answer one for now. The sequestration, the baseline from what I understand is virtually zero, so this is relaunching a new program with many components. We have about a $19 million program which is—$10 million will be in the Research, Development, and tests geological disposal in various environments including ocean and mines et cetera, and then in the Energy Research budgets is a brand new program focusing on the biological aspects of sequestration. This is a program which I think will be evaluated. We have a request for competitive proposals at the moment. We view it as, again, a kind of high risk, high payoff research. We definitely want to support it. We'll have to evaluate its rampup over the years.

Chairman SENSENBRENNER. The gentleman's time has expired. The gentleman from California, Mr. Calvert.

IMPACT OF PROPOSED PROGRAM ON GLOBAL WARNING

Mr. CALVERT. Thank you, Mr. Chairman. I for one, and I'm joined by many; I think some on this Committee, and certainly throughout the House and the Senate. I question the conclusions that the panel used on global warming as its justification for the proposals that you've articulated here before this Committee, and, in fact, I believe that if the Senate would vote today on the Kyoto Protocol it would enjoy very little support from either party. And, in fact, I understand the Administration has decided to push the vote off until 1999, and I suspect the outcome will change very little between now and then.

However, saying that, I'm from California, and we didn't need a treaty to lower our CO_2 emissions. If you looked at California, our CO_2 emissions are below, I believe, the 1990 levels now, and we did it without a United Nations Treaty Agreement. We did it for different reasons, and I think for good reasons. We had air quality problems and more specifically in my area of Riverside, California, but we did it through a very difficult process in California of lowering emissions of various types. We've gone through a process where we know what works and what doesn't work, and when we talk about tax incentives and we talk about these incentives and my friend from the Ways and Means Committee mentioned earlier, we try to simplify the tax code that may be contradictory.

However, saying that, we know that there are new diesel engines out there that are much more efficient, much cleaner, and that have lower CO_2 emissions, certainly lower particulate emissions; that we can use compressed natural gas for medium trucks that do most of the deliveries. We know that there's some practical things that you can do. California's already moved to regulate its energy. We hope that we're not made a part of the national effort to do that since we're already on a path towards doing that ourselves.

But saying all that, this Committee is in charge of doing basic research for types of energy such as wind, solar-geothermal which I think all of us support. But I don't like to hear about us potentially spending money on some of the proposals that may have very little outcome. I'd like to hear from you, Dr. Gibbons. You believe that we spent all the money that you proposed, on the programs that you proposed, how would that change the outcome of global warming?

Dr. GIBBONS. The farther, the deeper, you go into research the more you come to understand that you're dealing with an inherently uncertain future. The only way you can measure the outcome of research, in a sense, is to look backwards rather than forwards. And if we look backwards to the influence of research on our Nation's economy over the last half century, we find that the rate of return for research has been—accounts for about half of our economic growth over the last 50 years. In other words, it's had ubiquitous applications across our economy. In Energy, we try to choose those areas of research that are most promising in terms of discerning, discovering new fundamental options for our Nation, and as you move from the most fundamental research to the applied, we try to tackle those issues that have high potential leverage; high public payoff; that don't meet the hurdle rate for industry's with their pressures on near-term futures. Then we try to leverage it with partnerships with those industries.

Mr. CALVERT. Reclaiming my time, again, as you know, I'm in favor of fundamental research and believe that that should be done. I think that industry has a more important role as far as its application in the marketplace and that the market, in fact will make a determination whether one particular energy source is more practical than the other. What I have said that we know what works today and we can meet meaningful goals quicker by being practical about this in our policy if in fact we're going to move to tax incentives and whether we have the money to do that to give incentives to allow a turnover in the diesel trucks that we have in the fleet today in this country which is a big number, but that would have a big impact on, particularly, on particulates and other types of pollution or moving toward compressed natural gas on medium trucks. That would have a real impact very quickly and would help meet the goals that we would all like to get to cleaner air. Thank you.

Chairman SENSENBRENNER. The gentleman's time has expired. The gentlewoman from Texas, Ms. Johnson.

COSTS AND BENEFITS OF PROPOSED PROGRAM

Mr. JOHNSON. Thank you, Mr. Chairman, and thank you for continuing this hearing. I have some rather basic questions. When we move to the new technologies and offer the tax incentives for persons who might be able to purchase these vehicles it seems to me that we will have a greater demand on natural gas and, perhaps, less demand on imported gas which helps us to be less dependent worldwide. How, then, are we going to calculate that cost and that savings and the protection of that environment with not doing anything and allowing El Niño to continue and we have these natural disasters continue?

Dr. GIBBONS. I'm not sure I've caught your question, but let me see if I can respond as I understand it. That is, how can we take the change of fuel that go into the energy system, take fullest advantage of it? Fuels change all the time. We used to depend on whale oil and then wood and then coal and petroleum and now these other areas. What is going to happen is with the efficiencies we can put into these energy using systems, like automobiles, we can cut by a major amount the total amount of energy required to deliver those goods and services. It's a bottom line savings to us not only in terms of our resources but the cost of operating these automobiles. When we develop fuel sales that will enable us to, in the coming century, to disseminate our energy production system more broadly, we'll have a more resilient electricity production system. We'll save money and we'll have a more diversified source for our electricity. These are all enormous public savings. Savings in dollars, savings in resiliency of the system, and also will improve our economy because it's new markets not only here, but overseas. So our calculus is based on what can we do with technology to enable these things to happen and push us in that direction?

Ms. JOHNSON. Okay, the second part of my question is if we—the biggest outcry I've heard against any kind of change is cost to the industry and the cost to bring themselves into compliance. But if we do not come into compliance, it appears to me that what we continue to do is force ourselves into more uncertain conditions that take place within this environment, when we do nothing to change some of the dynamics in the environment.

And I still hear people, leaders of States and areas calling on the Federal Government and FEMA to assist when these natural disasters come, and as far as we can determine, they are being influenced by the environmental conditions we're in.

Dr. GIBBONS. Climate change will undoubtedly exacerbate some of the stresses that are already out there on the system. We now have a cost of about a billion dollars a week of natural disasters for the United States.

The insurance industry is extremely concerned about these rising costs. And climate change takes us in the direction of rapidly increasing those costs.

Ms. JOHNSON. Climate change without improvement, or just climate change, period?

Dr. GIBBONS. Climate change without action.

Ms. JOHNSON. Okay. Thank you. Did someone else want to comment, or is that complete?

Dr. MONIZ. Well, I was going to comment on your first question, if I might. Energy security clearly is a major goal and a major federal responsibility. I would just amplify what Jack said.

For example, on natural gas, as I said earlier, we are developing technologies, for example, to be able to bring natural gas from more remote locations and therefore, whether it's in gas or liquid form, and therefore add it to our domestic supply.

We estimate, for example, our membrane technology may provide a billion gallons of barrels of liquid just from North Slope gas alone.

Mr. GARDINER. The only thing that I was going to add was simply on your point about the costs of dealing with this issue, that what we're finding in the programs that we already have on climate change is that there are thousands of businesses and other institutions across the country that are signing up for the programs that we have today because it saves them money, not because it costs them money.

And so our view is that there are extremely cost-effective, in some cases, opportunities to reduce greenhouse gas emissions and save people money—very substantial opportunities over the course of the decade—and ones that can begin with existing technologies today and which will only get better as we develop even newer and better technologies over time.

Chairman SENSENBRENNER. The gentlewoman's time has expired.

Ms. JOHNSON. Thank you, Mr. Chairman.

Chairman SENSENBRENNER. The Chair would observe that I have seen no scientific evidence that greenhouse gases or global warming causes El Niño. Perhaps we can have a hearing on whether that happens later on.

The gentlewoman from Maryland, Mrs. Morella.

U.S. CAPABILITY OF MEETING KYOTO PROTOCOL EMISSIONS TARGET

Mrs. MORELLA. I want to thank you, Mr. Chairman, for this second hearing, and thank those panelists who are here testifying.

I guess what I really want to ask you is about the verity of this whole program. I note that $3.6 billion in tax credits, $2.7 billion in research. It appears from what I have read and heard that the United States is on track to produce 33 percent more greenhouse gases in 2010 than in 1990.

Therefore, if our President has promised that we would emit seven percent less by 1990, what's happening there? There's something wrong with that figuring. And will this achieve it?

I'd like to ask all of you, for whatever your expertise comments are on it. It just doesn't seem to figure out.

Dr. GIBBONS. Let me see if I can straighten the numbers. The numbers you quoted, I think are correct, except if you look at the bookkeeping of the things that happened in Kyoto, rather than a 7 percent decrease under the 1990, it's more like a 3 percent number because of the way the different gases are taken into account and some other matters—and the sinks of carbon.

But the fact is that our strong economic growth and our very low cost energy has caused us to increase our energy production and consumption quite rapidly, and we kind of hope that that economic growth will continue right straight on through the first part of the next decade.

This is very much unlike most of the other countries of the world, especially the industrial world. It's easy for Russia or some of the Western European countries to make these goals because their economies haven't been strong and robust. So it's good news and bad news for us.

At the same time, a change of that dimension of the order of 30 percent over a decade period, or a decade and a half, is a manageable one if we put our minds to it. The technology for doing most of that is already in hand, and the economics of it, in turn, I believe are very attractive if you look at it carefully.

And I went through this in the 1970's when we talked about energy efficiency changes. We've seen a 30 percent improvement in energy efficiency over that period of time, at the same time, energy prices were going down.

Mr. GARDINER. I would just add, Congresswoman, that in terms of the existing program, not the proposal that the President has made now, but the existing Climate Change Programs that we have, we have estimated that if we were to continue those through the period that you described, in essence the next decade, that they would eliminate about 20 percent or so of that gap that you identify.

Clearly, the President's initiatives will do more. The major factor that influences how much more they do—we'd like to have them do a lot—really depends on how businesses and others respond to the opportunities to invest in these technologies over the course of the next decade or so.

We, obviously, are hopeful that we can dramatically increase not only the rate of innovation, but the rate of investment in these more efficient and less polluting technologies in the short term stretching out over that decade. So we'd like to see that number not be 20 percent, but a much larger number.

But we're not sure of that; we can't guarantee it. But our hope is that by launching initiatives like this, we can eliminate much more of that gap that you identify by the time we get toward that period, and in essence, reduce what we need to do with other mechanisms beyond these research and technology programs that we're proposing now.

Dr. MONIZ. If I may quote a Chinese proverb, if you don't change direction, you will end up where you were headed. And I think the program, in terms of technology development and incentives, as they have both said, is in fact, to at least provide the options for a changed direction.

How much can one change in the time period of, say, 15 years? Well, Jack quoted previous experience in terms of improved efficiency. I noted earlier that we are 50 percent more energy intensive than other industrialized countries. There is room.

So, in the near term, efficiency is where the biggest gains would come from technology, and then later on, renewables. And then perhaps later on, even things like sequestration for use of fossil fuels.

Mrs. MORELLA. There's no doubt, I think, the direction is important, and I think the tax credits, I don't know how much they are really going to help as you measure it, but I think it's a good direction. I think all of us should begin to look at that—what's happening, we save buildings. I applaud NIST.

Of course, Mr. Bachula, under your direction also, for the work that's being done and what you articulated in this. I just think that what we're doing is using new math.

Chairman SENSENBRENNER. The gentlewoman's time has expired.

Mrs. MORELLA. What we've got to do is establish a culture that deals with this. Thank you.

Chairman SENSENBRENNER. Thank you. And last, but certainly not least, the gentlewoman from Michigan, Ms. Stabenow.

Ms. STABENOW. Thank you, Mr. Chairman. I appreciate the hearing and your tenacity in keeping us on track, so I have the opportunity to be——

Chairman SENSENBRENNER. The bell will ring in about three minutes, that's why.

CREATION OF MARKETS FOR ALTERNATIVE VEHICLES

Ms. STABENOW. Yes, I will be quick. Back to the issue on emissions—also representing Michigan, and my colleague from Michigan also spoke to the issue, certainly of jobs in the auto industry, first a comment.

We have seen very directly where the partnerships between the Federal Government and the Big Three automakers has made a difference in the Partnership for Next Generation Vehicles, the Advance Technology Project, the Auto Body Consortium, which has been one of the best ATP programs in terms of creating more efficiencies in the industry.

I think the industry should be applauded for its aggressiveness at this point, and that there is a critical role. We are now making electric cars in my District in Lansing, in part as a result of the ATP partnership that created the ability for new materials, as it relates to the ability to build electric cars.

My question relates to creating markets for these vehicles. I've had the opportunity to drive a natural gas vehicle. Certainly, there's much promise as it relates to emissions, the electric car, and so on.

My concern is that, first of all, are the tax credits enough? And second, what about infrastructure? If we are going to make this consumer-friendly, then the service station has to be more than a petroleum service station. We have a natural gas vehicle that could be on the market today, very, very important as it relates to the environment and emissions. We don't have the infrastructure.

If we're going to create the markets, how do we do that, number one. What are we doing? And secondly, I know that there has been a Presidential directive that relates to government fleets and encouraging alternative fuel vehicles as part of our fleets.

It seems to me we have a very critical leadership role to play in creating the markets by ourselves in government, purchasing these vehicles, and giving the automakers the confidence that, in fact, if they build them, people will come. So I would like your comments.

Mr. BACHULA. The ultimate question of whether or not there will be fleets of these new advanced cars on the road is posed by all of the issues that you raised. One is the cost to manufacturer. Is it a competitive price?

The concept cars that Chrysler showed, for example, at the auto show a month ago, they claimed would get about 73 miles per gallon; not quite with all of the PNGV kinds of goals in it, but they said there's about a $15,000 premium on manufacturing it right now, compared to an equivalent Intrepid.

But they brought that down from a $60,000 premium just two years ago, so with advanced work, we hope that these cars are going to be comparable in price to cars that people are familiar with today. And that's one part of the problem.

Whether a tax incentive can help make that even more attractive and reduce risk, whether first purchases of the first 50,000 such cars by the Federal Government might help, all of that might contribute down the line as these cars become available.

Ms. STABENOW. If I might just interrupt, we know that in general in the marketplace, the more volume, the price goes down, whether it's computers, whether it's cars or so on.

Mr. BACHULA. That's exactly right, and as you go through the curve, basically you can bring price down through experience. The question of infrastructure is an important one. The Partnership for a New Generation of Vehicles is peer-reviewed by the National Academy of Engineering each year, and they have raised the issue of infrastructure and whether it will be there when these kinds of cars are ready.

And we are in the process in the Administration of talking to the fuels industry, talking to others who may have to adjust their mix of products in order to be able to meet these kinds of new vehicles.

ROLE OF FEDERAL GOVERNMENT IN AUTOMOTIVE INDUSTRY INFRASTRUCTURE

Ms. STABENOW. Do you see a role for the Federal Government in that, or do you see that being an industry response at this point in terms of infrastructure? Do you have plans for any kinds of partnerships?

Mr. BACHULA. At the outset, I think there's clearly a role for us as just a facilitator, getting the guys who make the cars and the guys who make the fuel together to talk about what the possibilities are. And there probably are some kinds of advanced research activities going on in the Department of Energy with fossil fuels and alternatives. Fuels that you can make from natural gas, for example. That may be very, very relevant to this.

But some of these cars, some of these ideas, are very advanced. They will probably use a different kind of fuel. We have switched fuels before in this country. We have taken the lead out of gasoline, for example, and there's a process where you have to have some pumps that have one fuel in and some pumps that have another.

But it is quite possible to do that if we can sort of get our act together. And that's part of what this effort is all about.

Dr. MONIZ. If I may just add, very, very briefly, that we have a broad portfolio of activities. Gary mentioned the Fuels Program. I would just mention two other things. One is research along the lines of using new technologies which use the existing infrastructure, like gasoline-powered fuel cells.

Another is our Clean Cities Programs, which is precisely aimed at developing the infrastructure. We'd be very happy to brief you on that, if you'd like.

Chairman SENSENBRENNER. The gentlewoman's time has expired, and everybody's time has expired, except over on the floor where there are about 2 minutes left.

So I'd like to thank both witnesses and members for a very productive and informative discussion today. Time does fly when we're having fun. We're going to be back at it after the recess. The Committee is adjourned.

[Whereupon, at 11:54 a.m., the Committee was adjourned, to reconvene at the call of the Chair.]

APPENDIX 1: Answers to Post-Hearing Questions Submitted by Members of the Committee on Science

COMMITTEE ON SCIENCE
U.S. HOUSE OF REPRESENTATIVES

Hearing
on

The Road from Kyoto—Part 2:

Kyoto and the Administration's Fiscal Year 1999 Budget Request

Thursday, February 12, 1998

Post-Hearing Questions
Submitted to

The Honorable John H. Gibbons
Assistant to the President for Science and Technology
and
Director, Office of Science and Technology Policy

Post-Hearing Questions Submitted by Chairman Sensenbrenner

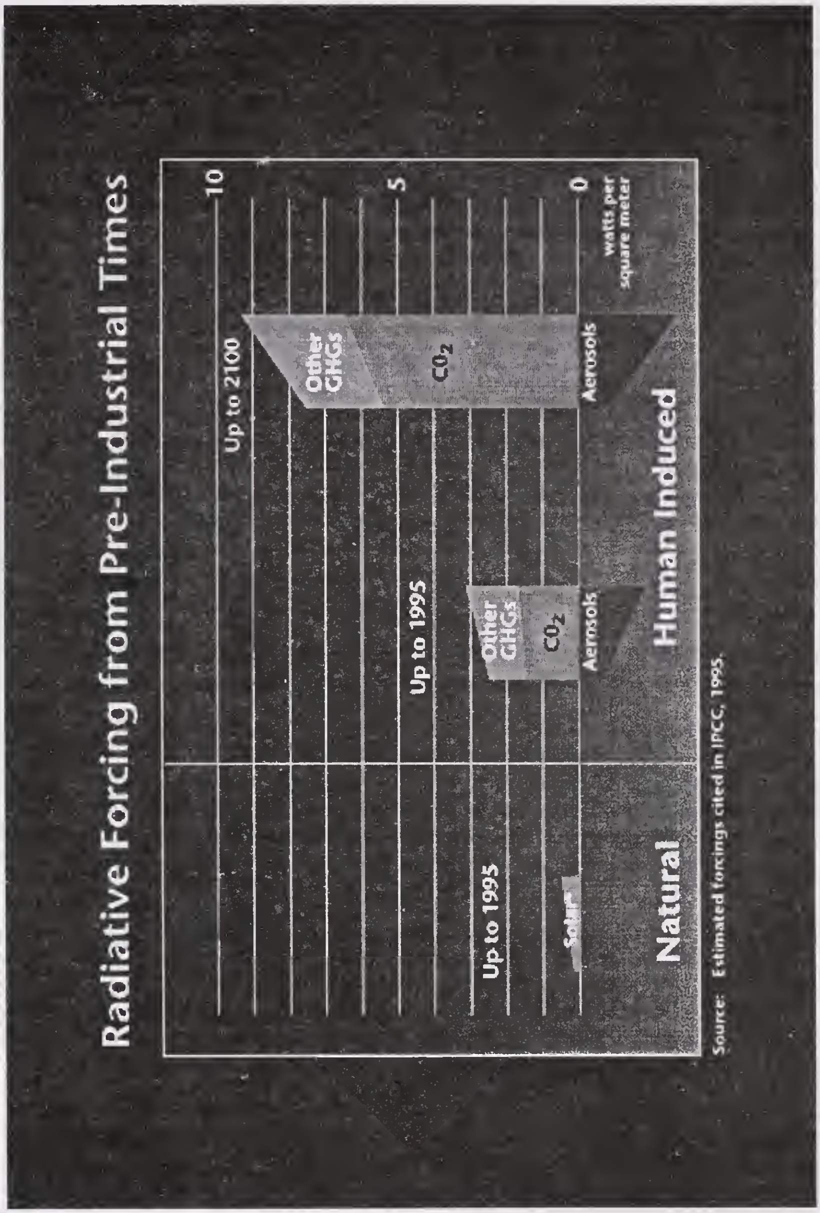
"Clear and Compelling Evidence" That Human Activities Are Causing Climate Change

Q1. You state on page 2 of your testimony that "the scientific evidence that climate change is occurring, and that human activities are playing a significant role in causing such change, is clear and compelling." However, at a recent American Meteorological Society international meeting on Global Climate Studies in Phoenix, Arizona, David Rind and Judith Lean of NASA demonstrated that about half of the observed global warming is ascribed to solar activity. These means that only about 0.5°F of the warming experienced in the last century could be due to other causes, including human activity. Are you familiar with this research, and if so, how does the interplay of solar activity affect climate?

A1. In seeking to be even more certain that human activities are indeed affecting climate the USGCRP agencies support a number of scientists whose research focuses on attempting to better quantify the contributions of natural influences on the climate. David Rind of NASA and Judith Lean of the Naval Research Laboratory are two of these scientists and they are making important advances that we follow closely.

What we understand their research to show is that variations in solar radiation correlate well with changes in the Earth's climate over several centuries prior to the 20th century. As to magnitudes of natural and human changes, virtually all studies show that natural factors dominated global-scale climate changes prior to the 20th century, and that human influences are apparently dominating in the second half of the 20th century, with even greater dominance predicted for the 21st century. The Rind-Lean results also suggest that solar variability did contribute to the warming during the first half of this century, with the solar effect peaking at about 0.5° F around 1940. This warming effect has not continued fully to the present (solar radiation goes both up and down over time in cycles), so that this full amount cannot be subtracted from the 1.0 to 1.3° F warming that has occurred since the mid-19th century.

In summary, we believe that the solar variation studies show that the climate is indeed responsive to change in the Earth's radiation balance and that model simulations of climate changes since 1850 are improved by consideration of solar and human influences. However, it is quite clear that if the atmosphere responds to the radiation changes of the solar cycle, it will respond even more to the dramatically greater forcing from greenhouse gases. (See attached chart summarizing the IPCC's findings). Together, these results enhance our confidence in the predictions of even more significant human-induced climate change during the 21st century.


Radiative Forcing from Pre-Industrial Times
10
5
0
watts per square meter
Up to 2100
Other GHGs
CO2
Aerosols
Up to 1995
Other GHGs
CO2
Aerosols
Human Induced
Up to 1995
Solar
Natural
Source: Estimated forcings cited in IPCC, 1995.

<u>Climate Change and Extreme Events</u>

Q2. **Your testimony on page 4 states that, "More precipitation is likely to occur in 'extreme' downpours, where large amounts of rain fall in a short period. Some areas will be threatened by increased flooding, while others will suffer through an increased incidence of drought, as continental interiors become warmer and drier." However, the 1995 IPCC report, *The Science of Climate Change,* concludes on page 336: "Except *maybe* for precipitation, there is little agreement between models on changes in extreme events [emphasis added]." And even concerning precipitation, it concludes: "*Several* models *suggest* an increase in the precipitation intensity, *suggesting* a *possibility* for more extreme rainfall events [emphasis added]."**

Do you agree with these IPCC conclusions?

A2. I accept the 1995 IPCC findings as a typically cautious summary of worldwide scientific understanding based on scientific findings through early 1995. Because of the importance of potential changes in extreme events, research in this area has intensified. The increased confidence expressed in my testimony reflects the developing understanding and the emerging scientific findings.

Analyses by Tom Karl of NOAA's National Climatic Data Center show that the precipitation increases we are seeing over the last century are coming primarily as high intensity, extreme events. Total rainfall has increased in the U.S. by 5-10% in the last century, and it is the rainfall events of more than 2 inches per day that have increased the most.

It is well accepted that the increased energy associated with global warming will lead to more evaporation and more water vapor in the atmosphere, which will mean in turn more energy and water vapor to be converted into intense rainstorms as convection occurs. Just as summer and warm region (e.g., El Niño affected) rainstorms produce much more rainfall in shorter times than do winter and cold region storms, there is a very strong foundation for saying, as I did, that "More precipitation is likely to occur in 'extreme' downpours."

Stronger downpours will also lead to increased threats of flooding. And warmer temperatures will lead to increased evaporation (so dryness and then drought) in regions where precipitation events are now infrequent and may in the future be missed by the intensified storms. Our natural hazards studies suggest we should be very concerned about the trend toward an increased frequency and intensification of extreme precipitation events.

Q3. **With respect to your statement on page 4 that "Some areas will be threatened by increased flooding, while others will suffer through an increased incidence of drought, as continental interiors become warmer and drier," isn't it also likely to be true that some areas will have decreased flooding and decreased incidence of drought"?**

A3. Yes. Some areas will experience decreased flooding and others will have a decreased incidence of drought. Overall, however, precipitation is projected to increase worldwide, and intensity of precipitation is expected to increase with warmer weather, so when it does rain, flooding will be more likely. Further, already drought-prone areas are likely to become increasingly arid because of additional warming.

Documentation of 1997 Temperature Statistics

Q4. **Your testimony on page 4 also states that "new results from the National Oceanic and Atmospheric Administration (NOAA) show that 1995 has been surpassed by 1997, and that nine of the last eleven years are among the warmest ever recorded (Figure 1). 1997 also shows up as the warmest year in data records maintained by the United Kingdom Meteorological Office and the NASA Goddard Institute of Space Studies, meaning that the three most comprehensive and accurate long-term surface data records all indicate continued warming of our planet."**

Q4.1 **Please provide a copy of NOAA report and accompanying data/statistics referred to in your statement above.**

A4.1 Attached are a NOAA graph of the annual global temperature index and a figure showing global temperature anomalies for 1997 and a press release from NOAA discussing the results of an analysis by a team led by Dr. Tom Karl. Further details can be found on the NOAA/NCDC home page at http://www.ncdc.noaa.gov/ol/climate/research/1997/climate97.html.

UNITED STATES DEPARTMENT OF
COMMERCE
NEWS
WASHINGTON, D.C. 20230

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

NOAA 98-1

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FOR IMMEDIATE RELEASE
1/8/98

1997 WARMEST YEAR OF CENTURY, NOAA REPORTS

1997 was the warmest year of this century, based on land and ocean surface temperature data, reports a team of scientists from the National Oceanic and Atmospheric Administration's National Climatic Data Center in Asheville, N. C.

Led by the center's Senior Scientist Tom Karl, the team analyzed temperatures from around the globe during the years 1900 to 1997 and back to 1880 for land areas. For 1997, land and ocean temperatures averaged three-quarters of a degree Fahrenheit above normal. (Normal is defined by the mean temperature, 61.7 degrees F, for the 30-years 1961-90.) The 1997 figure exceeds the previous record warm year, 1990, by 0.15 degrees Fahrenheit.

The record-breaking warm conditions of 1997 continues the pattern of very warm global temperatures. Nine of the past eleven years have been the warmest on record.

"Land temperatures did not break the previous record set in 1990, but 1997 was one of the five warmest years since 1880," said Karl. Including 1997, the top ten warmest years over the land have all occurred since 1981, and the warmest five years all since 1990. Land temperatures for 1997 averaged three-quarters of a degree above normal, falling short of the 1990 record by one-quarter of a degree.

Ocean temperatures during 1997 also averaged three-quarters of a degree above normal, which makes it the warmest year on record, exceeding the previous record warm years of 1987 and 1995 by 0.3 of a degree Fahrenheit.

With the new data factored in, global temperature warming trends now exceed 1.0 degree Fahrenheit per 100 years, with land temperatures warming at a somewhat faster rate. "It is likely that the sustained trend toward increasingly warmer global temperatures is related to anthropogenic increases in greenhouse gases," Karl said.

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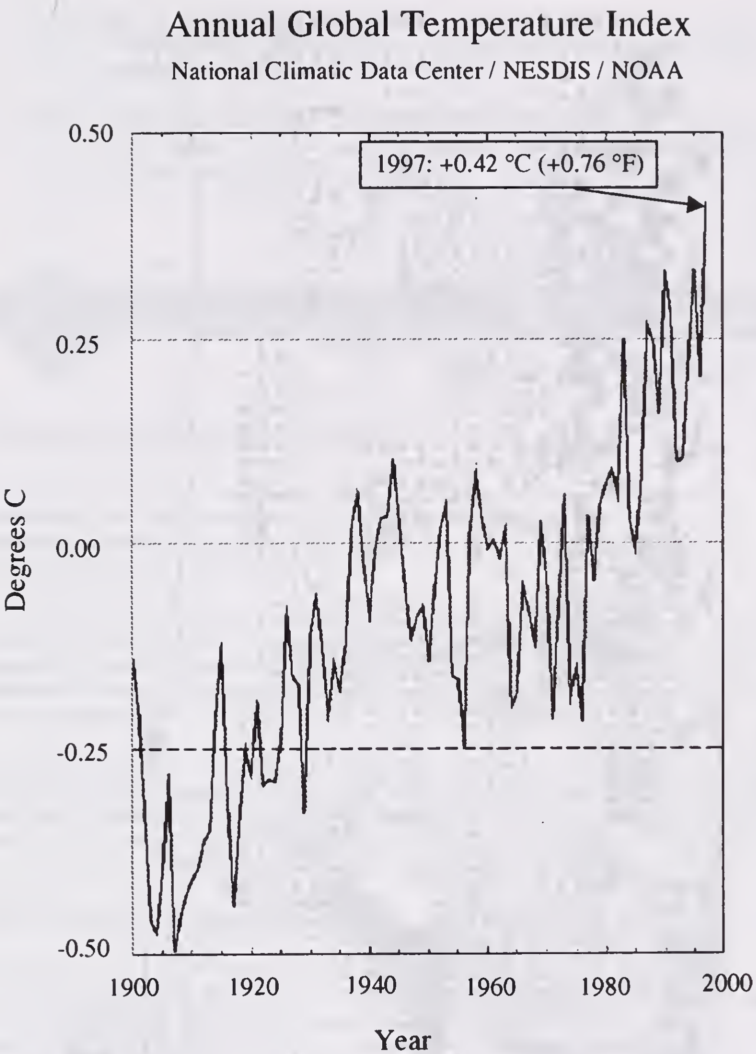

The global average temperature of 62.45 degrees Fahrenheit for 1997 was the warmest on record, surpassing the previous record set in 1995 by 0.15 degrees Fahrenheit. The chart reflects variations from the 30-year average (1961-1990) of the combined land and sea surface temperatures.

Global Temperature Anomalies 1997

Q4.2 **Please provide a copy of the Goddard Institute for Space Studies/NASA confirmation and accompanying data/statistics referred to in your statement above.**

A4.2 Attached is a copy of the analysis of global temperatures for 1997 prepared by scientists at the National Aeronautics and Space Administration's Goddard Institute for Space Studies.

NASA Goddard Institute for Space Studies **Research**

Earth Observations

Global Temperature Trends

The focus of GISS research is the study of climate -- the normal or average state of the atmosphere -- and climate change. A major problem for the detection of climate trends is the enormous variability of the atmosphere, which can overshadow and disguise any trends, especially in regional studies.

In climate model experiments, this problem can be dealt with in various ways, depending on the nature of the experiment. For sensitivity studies one can increase the forcing to get a good signal-to-noise ratio; for studies of transient phenomena one may look at an ensemble of many model runs with slightly differing initial conditions; and for control or equilibrium runs one may average over a long time period.

For observational studies, the problem is more difficult. Data from meteorological stations are available only from about 1850 to the present, with incomplete coverage in space and often with temporal gaps as well. GISS has set up a system to get the most out of the available surface air temperature data, developing and refining techniques to eliminate outliers and station discontinuities, and to combine the data into one coherent data set.

1997 Temperature Observations

Global surface air temperature in 1997 was warmer than any previous year this century, marginally exceeding the temperature of 1995. The 1990s are significantly warmer than any previous decade in the period of instrumental data, with the four warmest years of the century being 1990, 1991, 1995 and 1997. Regionally, the eastern part of the United States was cooler than normal in 1997.

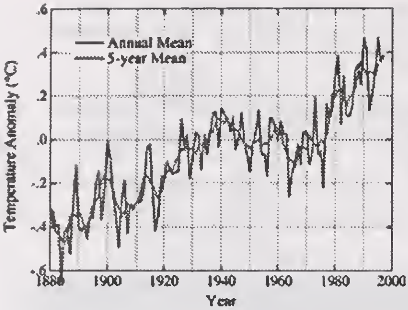

Fig. 1: Near-global annual-mean surface air temperature change, based on meteorological station network. **(Click on figure to view full-size image.)**

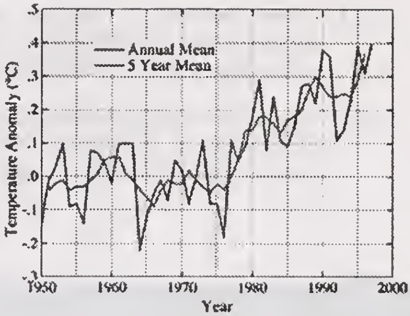

Fig. 2: Global land-ocean surface temperature index, which combines sea surface temperature measurements for ocean areas with surface air temperature measurements at meteorological stations. **(Click on figure to view full-size image.)**

Our estimated global surface temperature change for the calendar year (Jan-Dec) is shown in Figures 1 and 2. Figure 1 is based on the land-based meteorological station network. Figure 2 combines satellite measurements of ocean surface tempeature with the land data to obtain a more representative global-mean temperature index (Reynolds and Smith 1994).

In most years the land-based and the land-plus-ocean analyses are in close agreement. However, they differ noticeably in 1997 because of the unusually high temperatures in the tropical Pacific Ocean associated with one of the strongest El Niño events on record.

In the land-based-analyses (Figure 1), 1997 is the fourth warmest year in the record. In the land-ocean temperature index, 1997 is the warmest year, being slightly (about 0.01°C) warmer than 1995.

The temperature differences among the warmest years are small and not significant in all cases, as the relative uncertainties are estimated to be a few hundredths of a degree Celsius. However, it is noteworthy that the 1990s are significantly warmer than the 1980s or any previous decade in the century.

Temperature Maps

The monthly temperature anomalies in 1997, relative to the period 1951-1980 are shown in Figure 3. These maps highlight the appearance and rapid growth of the El Niño warming off the west coast of South America beginning in the spring of 1997.

The annual temperature anomalies for each of the past 12 years, relative to the period 1951-1980, are shown in Figure 4. It was cool in the eastern United States in 1997, as it was in 1996.

The coolness in much of the United States during the past two years is not typical of the preceding 10 years. It is noteworthy that the past two years have been warm in the region of Newfoundland Bay-South Greenland, in contrast with the cold conditions that there were in the previous 10 years.

Fig. 3: Monthly temperature anomalies in 1997, relative to the 1951-1980 mean. **(Click on figure to view full-size image.)**

Discussion

Global surface temperature was unusually high in 1997. Indeed, when averaged over land and ocean, global surface temperature exceeded the previous record high of 1995 by a slight amount. Part of the current global warmth is associated with the tropical El Niño, without which a record global temperature would probably not have occurred. Thus, the 1997 global warmth does not add much to the evidence of long-term global warming that was not already apparent from temperatures in previous years of the 1990s. However, it does reaffirm that the decade of the 1990s is significantly warmer than the 1980s.

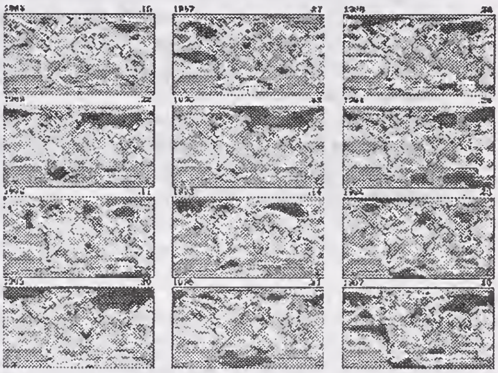

Fig. 4: Annual temperature anomalies for the past 12 years (1986-1997), relative to the 1951-1980 mean. **(Click on figure to view full-size image.)**

The observed changes in global mean temperature are not large enough to be noticed readily by people. Monthly-mean and even annual-mean local temperature anomalies are usually larger than these global mean temperature changes. Thus, the occurrence of negative temperature anomalies over much of the United States during the past two years more than masks the small global warming.

The year-to-year fluctuations in regional climate anomalies at middle and high latitudes are largely chaotic (as opposed to forced or deterministic) (Hansen et al. 1997), but there is some association of regional changes with cycles such as the North Atlantic Oscillation. This topic is beyond the scope of the present discussion, but some relevant references are included below.

Further Information

Other GISS pages related to this research are:

- Global Temperature Trends, 1996 Summation
- Surface Air Temperature Analyses Datasets

Contacts

Please address all inquiries regarding GISS surface temperature trends analysis to James E. Hansen. Other GISS scientists involved in this research are Reto A. Ruedy, Makiko Sato, and Jay Glascoe.

References

- Hansen, J., A. Lacis, R. Ruedy, M. Sato, and H. Wilson 1993 How sensitive is the world's climate? *Natl. Geog. Res. Exploration* 9, 142-158.
- Hansen, J., R. Ruedy, M. Sato, and R. Reynolds 1996. Global surface air temperature in 1995: Return to pre-Pinatubo level. *Geophys. Res. Lett.* 23, 1665-1668.
- Hansen, J., et al. 1997. Forcings and chaos in interannual to decadal climate change. *J. Geophys. Res.* **102**, 25679-25720.
- Hurrell, J.W. 1995. Decadal trends in the North Atlantic oscillation: Regional temperatures and precipitation. *Science* **269**, 676-679.
- Reynolds, R.W. and T.M. Smith 1994. Improved global sea surface temperature analyses. *J. Climate* 7, 929-948.

Q4.3 Please provide a copy of the East Anglia University confirmation and accompanying data/statistics referred to in your statement above.

A4.3 Attached is a copy of a brief report by the Meteorological Office of the United Kingdom's Hadley Centre for Climate Prediction and Research on their finding that 1997 was the warmest year on record.

Global and regional climate in 1997

D E Parker, E B Horton, and M Gordon.

Hadley Centre, Meteorological Office, Bracknell, U.K.

February 5, 1998

Global climate

The average temperature near the surface of the earth in 1997 was the highest so far recorded. an estimated 0.43 deg C higher than the 1961-1990 average (Figure 1a). This is based on air temperature data collected from over 1,000 land-based weather stations (Jones, 1994), plus sea surface temperatures (Parker et al., 1995) measured from the Voluntary Observing Fleet of about 7,000 ships and 1,000 buoys. The previous warmest year, 1995, was 0.38 deg C warmer than average (Figure 1a). However, although 1997 was nominally warmer than 1995, the difference is not statistically significant because the standard error of recent global, annual averages is about 0.06 deg C owing to large gaps in the data coverage, especially in the Arctic and Antarctic (Jones et al., 1997). Overall global warming since the late nineteenth and early twentieth century is about 0.6 deg C (Figure 1a).

The annual anomaly of 0.51 deg C for the Northern Hemisphere (standard error about 0.07 deg C) was the second highest after 1995 (Figure 1b). The Southern Hemisphere had an overall temperature anomaly of 0.35 deg C, the highest on record (Figure 1c) but with a standard error of about 0.10 deg C(Jones et al., 1997). The tropical belt 30°N to 30°S also had its warmest year. The southern extratropics had their equal warmest year with 1993. The northern extratropics were warmer in both 1990 and 1995.

The leading feature of 1997 was the very strong El Niño event which developed during northern spring. A time-series of sea surface temperature for the Niño 3.4 area (5°N - 5°S, 170° - 120°W) since 1871 shows that the highest temperatures were in 1997 (Figure 2). Sea surface temperature anomalies exceeded 3 deg C over a large area of the eastern tropical Pacific by northern autumn, with anomalies up to 5 deg C locally (Figure 3a), and with a large area of the tropical eastern Pacific warmer than the 98th percentile (Figure 3b). Even the annual pattern (Figures 4a,b) shows warmth exceeding the 98th percentile in parts of the tropical eastern Pacific. The area with sea surface temperatures more than 4 deg C above the 1961-1990 average in the eastern tropical Pacific exceeded 4 million km^2 in October (a 10° latitude x 10° longitudebox at the equator is about 1.25 million km^2). The previous greatest area exceeding 4 deg C above the 1961-1990 average was about 2 million km^2 during the very strong El Niño event of 1982-3. Whether this is really the strongest El Niño event in the instrumental record is uncertain, however, owing to the global warming of 0.6 deg C over that time.

The Pacific near the North American coast was warmer than usual throughout 1997, giving the strong annual anomalies, relative to 1961-1990 average, above the 98th percentile in Figure 4. Central Siberia west of Lake Baikal was also unusually warm, except in summer. The North Atlantic from Labrador to Ireland was persistently warmer than normal in 1997. Only small areas in the southeast Atlantic and over the Himalayas were colder than the 2nd percentile in 1997 as a whole.

According to radiosonde measurements from about 400 land- (or island-) based stations worldwide, the lower troposphere in 1997 was not significantly warmer than in 1996 in either hemisphere or the globe. On a global average, lower tropospheric temperatures were close to the 1971-1990 average (Figure 5). Warming might have been expected in 1997 owing to the strong El Niño event, but it is often delayed. This delay in the warming influence of a strong El Niño was also apparent in 1982-3. Because the coverage of radiosonde stations is not truly global, with large gaps especially over the oceans and tropical continents, we used temperature anomalies calculated from the USA's National Centers for Environmental Prediction (NCEP) Reanalysis (Kalnay et al., 1996) to guide a full global interpolation between radiosonde stations' anomalies before constructing Figure 5. We have adjusted the NCEP values where necessary, to agree as far as possible with our radiosonde data, to minimise any bias which may have arisen from the NCEP model. The NCEP reanalysis was created by assimilating all available data since 1958 into the analysis module of a state-of-the-art weather forecasting model, resulting in a series of globally-complete fields which is more self-consistent than that output by operational models which undergo progressive changes.

In the lower stratosphere, radiosonde and satellite sounding data indicate another very cold year in 1997 in both hemispheres (Figure 5). The stratospheric radiosonde data used in Figure 5 have, where possible, been adjusted for known instrumental changes since 1979, using the Microwave Sounding Unit MSU4 retrievals (Spencer and Christy, 1993) as a reference. This was necessary because instrumental improvements, such as improved shielding from solar radiation, tend to induce spurious stratospheric cooling, often exceeding 2 deg C (Parker et al. (1997)). In a lower-stratospheric layer equivalent to that sampled by MSU4, the Southern Hemisphere had its coldest year. In the Northern Hemisphere, 1995 was colder than 1997, but an overall cooling trend continues.

Figure Captions

Figure 1. Annual combined land surface air and sea surface temperature anomalies (°C) for the period 1860-1997, with respect to the average for 1961-1990. The smooth curves were created from the annual values using a 21-point binomial filter to highlight the interdecadal variations. (a) Globe; (b) Northern Hemisphere; (c) Southern Hemisphere.

Figure 2. Sea surface temperature anomalies (deg C relative to 1961-1990) for the Nino 3.4 area (5°N - 5°S, 170° - 120°W), January 1871 through December 1997. Monthly values were smoothed with a 21-point binomial filter so as to pass variations on time scales of a few seasons and longer. The dates on the x-axis correspond to the end of the year. The data were taken from version 3.0 of the Global sea-Ice and Sea Surface Temperature data set (GISST). This was constructed from the data of Parker et al. (1995) by projection onto high- resolution eigenvectors for ocean basins plus a global low-pass, low-resolution "climate change" eigenvector, followed by superposition of the original data with a light smoothing.

Figure 3. (a) Surface temperature anomalies (deg C relative to 1961-1990) for the season September to November 1997. (b) As (a), but expressed as percentiles of 3-parameter gamma distributions fitted to 1961-1990 data for the same season in each 5 deg. latitude x 5 deg. longitude pixel. At least 2 months' data are required for a pixel to be assigned an anomaly or a percentile. The data used are sea surface temperatures from the Hadley Centre and land surface air temperatures processed by the Hadley Centre and the University of East Anglia.

Figure 4. As Figure 3 but for the whole of 1997. The temperature value of each pixel is derived from at least 1 month's data in each of 4 three-month seasons (January to March, etc.). The percentiles in (b) are based on 3-parameter gamma distributions fitted to 1961-1990 data processed in the same way.

Figure 5. Zonally-averaged temperature (deg C) in the troposphere and lower stratosphere in 1997, with respect to 1971-1990, based on a blend of worldwide radiosonde data and the NCEP Reanalysis (see text). The data for 150, 100 and 50 hPa are adjusted to compensate for instrumental changes since 1979 at radiosonde stations, using the Microwave Sounding Unit MSU4 retrievals as a reference.

FIG. 1.

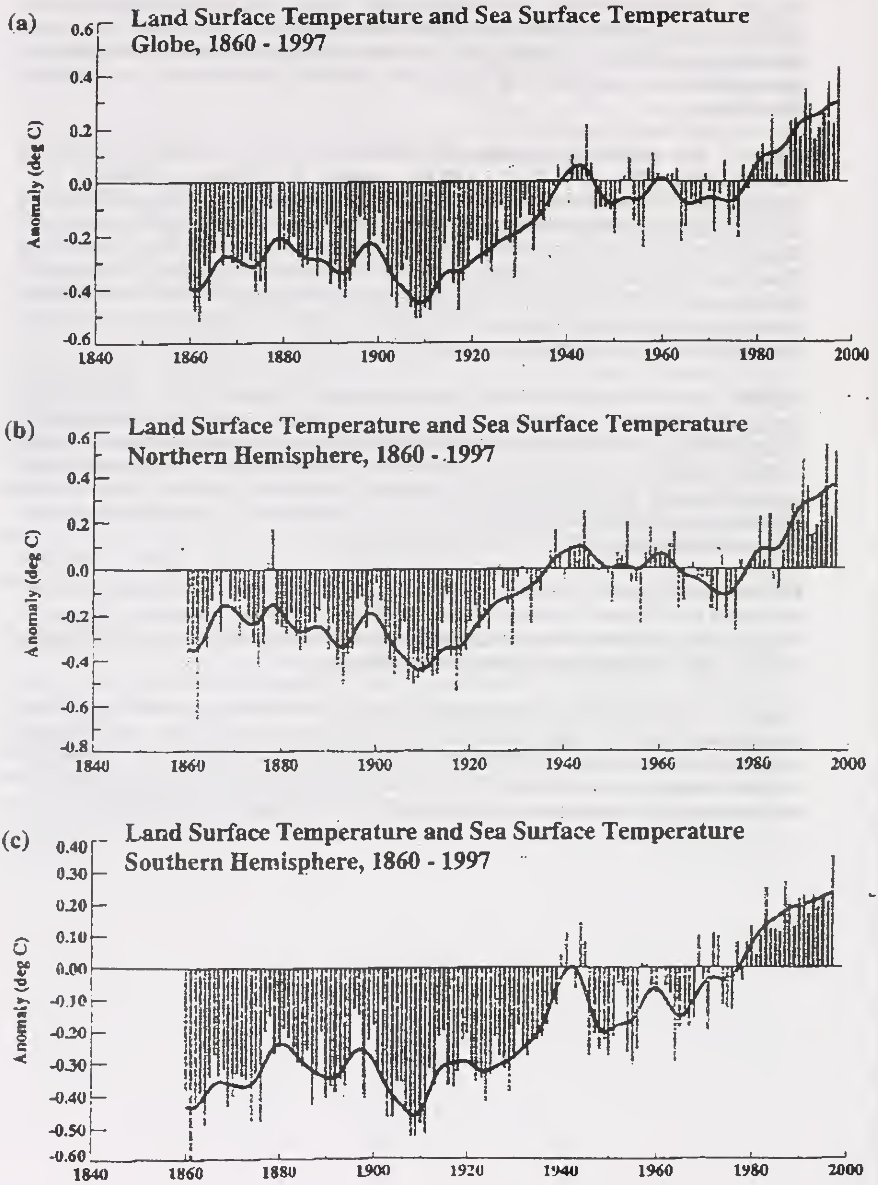
(a)
Land Surface Temperature and Sea Surface Temperature
Globe, 1860 - 1997
Anomaly (deg C)
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
1840
1860
1880
1900
1920
1940
1960
1980
2000
(b)
Land Surface Temperature and Sea Surface Temperature
Northern Hemisphere, 1860 - 1997
Anomaly (deg C)
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
1840
1860
1880
1900
1920
1940
1960
1980
2000
(c)
Land Surface Temperature and Sea Surface Temperature
Southern Hemisphere, 1860 - 1997
Anomaly (deg C)
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
-0.50
-0.60
1840
1860
1880
1900
1920
1940
1960
1980
2000

Fig. 2

FIG. 2.

Smoothed, Monthly, Sea-Surface Temperature Anomalies for Nino 3.4 based on GISST

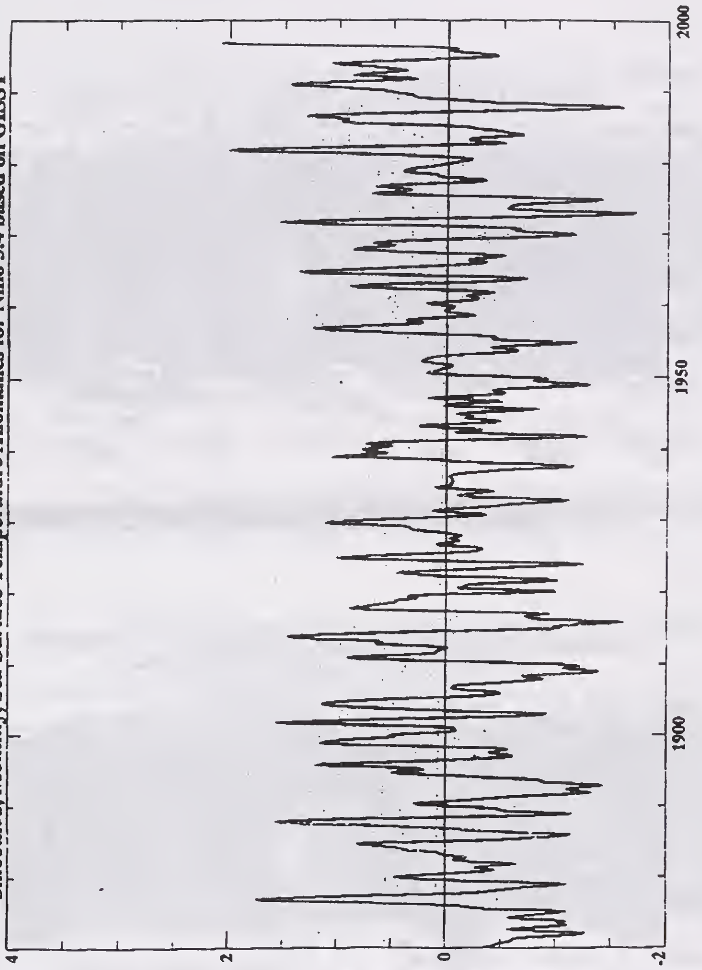

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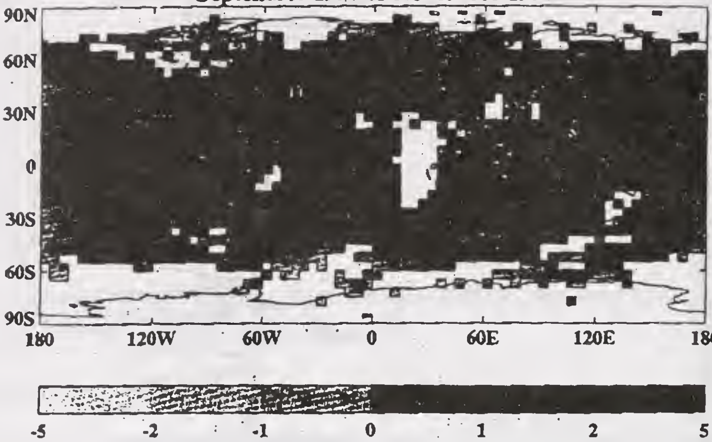
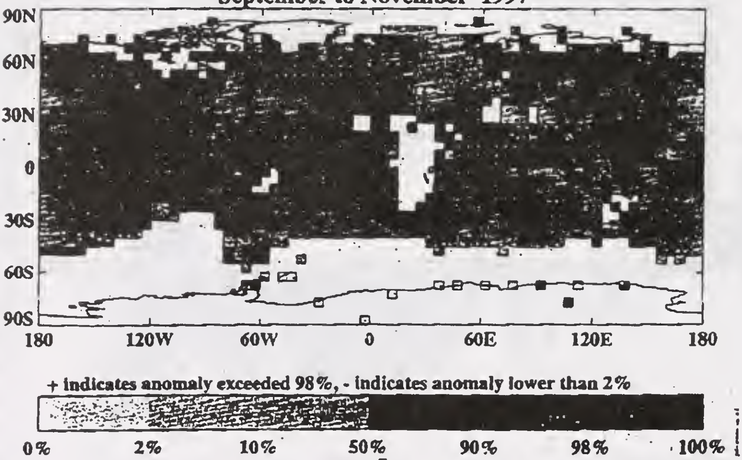
FIG 3.

Surface Temperature Anomalies (^{O}C, w.r.t. 1961-90)
September 1997 to November 1997

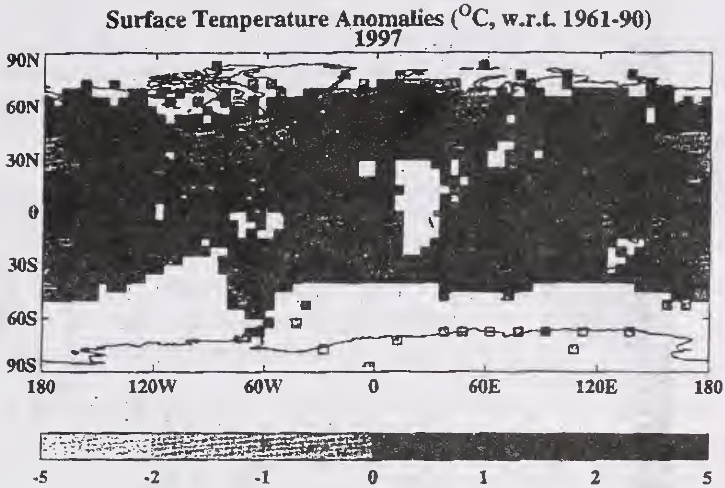


Surface Temperature Anomaly Percentiles (w.r.t. 1961-90)
(Anomalies fitted to Gamma Distributions)
September to November 1997



Land: Jones (J. Climate, 1994) Ocean: Parker et al (Climatic Change, 1995)

FIG. 4


Surface Temperature Anomalies (°C, w.r.t. 1961-90)
1997
90N
60N
30N
0
30S
60S
90S
180
120W
60W
0
60E
120E
180
-5
-2
-1
0
1
2
5

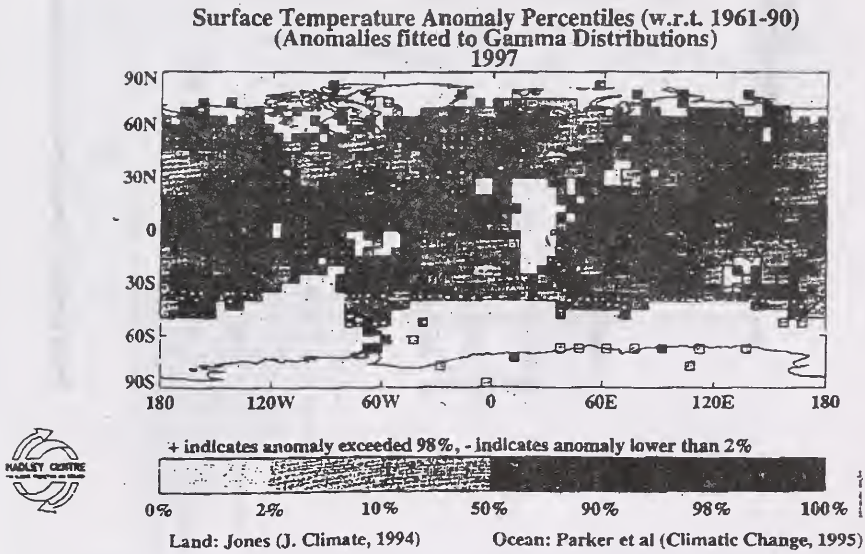
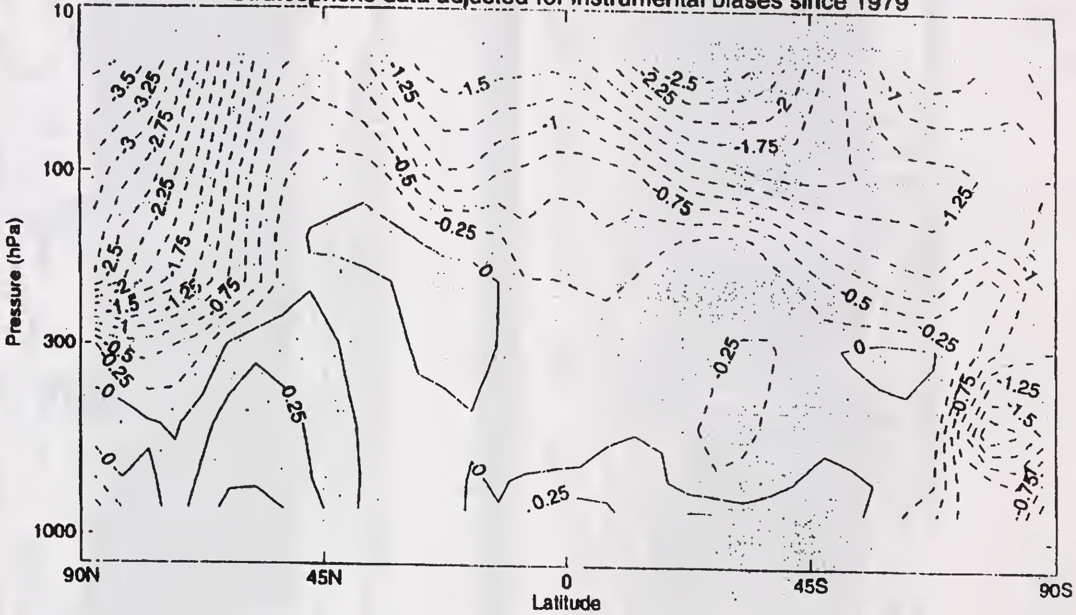

Surface Temperature Anomaly Percentiles (w.r.t. 1961-90)
(Anomalies fitted to Gamma Distributions)
1997
90N
60N
30N
0
30S
60S
90S
180
120W
60W
0
60E
120E
180
+ indicates anomaly exceeded 98%, - indicates anomaly lower than 2%
0%
2%
10%
50%
90%
98%
100%
Land: Jones (J. Climate, 1994)
Ocean: Parker et al (Climatic Change, 1995)
HADLEY CENTRE

FIG. 5.

Zonal mean temperature (deg C) 1997 w.r.t. 1971-90
Stratospheric data adjusted for instrumental biases since 1979



Hadley Centre for Climate Prediction and Research

Plotted 5.2.98

Q4.4 Please document your statement that "The nine warmest years of the century have occurred in the past 11 years."

A4.4 NOAA's National Climatic Data Center receives and archives data from land stations, ships of opportunity and NOAA satellites around the world. Based on these data and an extensive list of peer-reviewed articles, they have compiled statistics for global surface temperatures during the past century. The details of these data are provided on the NCDC home page at http://www.ncdc.noaa.gov/ol/climate/research/1997/climate97.html. A sample of the information on the Web site is attached.

NCDC / Climate Resources / Climate Research / Climate of 1997 / Search / Help

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National Oceanic and Atmospheric Administration

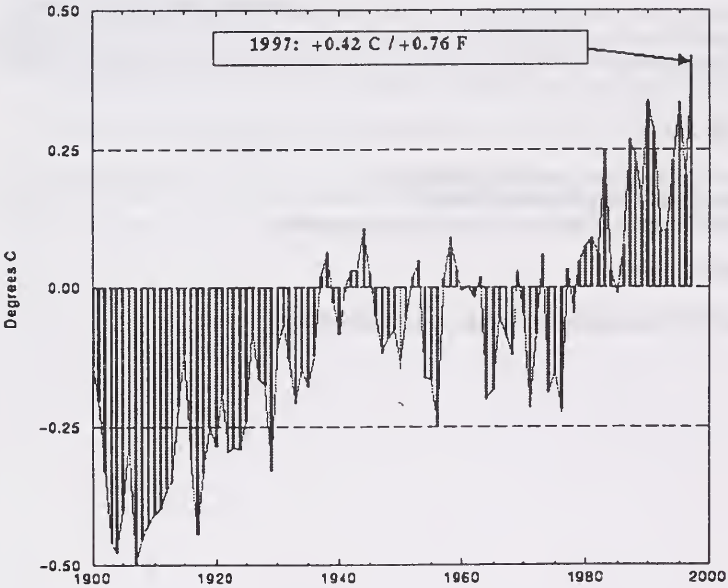
The Climate of 1997
Global Temperature Index:
1997 Warmest Year of Century

Rob Quayle, Tom Peterson, Catherine Godfrey, Alan Basist
National Climatic Data Center, Asheville, NC

January 12, 1998

Global Temperature Index

National Climatic Data Center / NESDIS / NOAA



1997 was the warmest year of this century, based on land and ocean surface temperature data, reports a team of scientists from the National Oceanic and Atmospheric Administration's National Climatic Data Center in Asheville, NC.

Led by the Center's Senior Scientist Tom Karl, the team analyzed temperatures from around the globe during the years 1900 to 1997 and back to 1880 for land areas. For 1997, land and ocean temperatures averaged three quarters of a degree Fahrenheit (F) (0.42 degrees Celsius (C)) above normal. (Normal is defined by the mean temperature, 61.7 degrees F (16.5 degrees C), for the 30 years 1961-90). The 1997 figure exceeds the previous warm year, 1990, by 0.15 degrees F (0.08 degrees C).

The record-breaking warm conditions of 1997 continues the pattern of very warm global temperatures. Nine of the past eleven years have been the warmest on record.

Land temperatures did not break the previous record set in 1990, but 1997 was one of the five warmest years since 1880. Including 1997, the top ten warmest years over the land have all occurred since 1981, and the warmest five years all since 1990. Land temperatures for 1997 averaged three quarters of a degree F (0.42 degrees C) above normal, falling short of the 1990 record by one quarter of a degree F (0.14 degrees C).

Ocean temperatures during 1997 also averaged three quarters of a degree F (0.42 degrees C) above normal, which makes it the warmest year on record, exceeding the previous warm years of 1987 and 1995 by 0.3 of a degree F (0.17 degrees C). The warm El Nino event (depicted as Sea Surface Temperature Anomalies) contributed to the record warmth of the oceans this year.

With the new data factored in, global temperature warming trends now exceed 1.0 degree F (0.55 degrees C) per 100 years, with land temperatures warming at a somewhat faster rate. ***"It is likely that the sustained trend toward increasingly warmer global temperatures is related to anthropogenic increases in greenhouse gases",*** Karl said.

The analysis was based on separately examining land data using the Global Historical Climatology Network, ocean data using the National Centers for Environmental Prediction (NCEP) - Reynolds Sea Surface Temperatures (SST), blended with the United Kingdom Meteorological Office Long Term SST analysis and a global surface temperature index that combined the ocean and land data.

See Also...

- Anomaly Time Series (Land, SST, and Index)
- Global Surface Temperature Anomalies
- Lower Tropospheric and Lower Stratospheric Temperatures

Additional Graphics

- US Statewide Ranks of 1997 Temperature and Precipitation

- Time Series Plot of Annual Precipitation
- Annual Anomalies of Precipitation - Global

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http://www.ncdc.noaa.gov/ol/climate/research/1997/climate97.html
Last Updated 26 Aug 98 by Catherine Godfrey cgodfrey@ncdc.noaa.gov

Land- and Sea-Based Versus Satellite Temperature Measurements

Q5. Your testimony on page 4 says that 1997 was the warmest year on record. However, the land-based temperature data upon which this claim is based do not comport with satellite data, which show a slight cooling trend (-0.05°C per decade) over the last 19 years in the layer from about 5,000 to 30,000 feet. In fact, 1997 was the 8th coolest year in the satellite record, just slightly less than the 19-year average.

Q5.1 How do you account for the divergence between the trends in land-based and satellite temperature records over the past two decades?

A5.1 Surface-based temperature measurements of the ocean, sea surface and land surface have been made for the last 110 years, and definitively show that the Earth has warmed by about 1 degree F over this time. Satellite records have only been available for the past 19 years. That is too short a time period to accurately detect long-term temperature trends, given the natural cycles (e.g. El Niño and solar radiation) and random events (e.g. volcanic eruptions) that affect the global climate. The somewhat longer weather balloon record of atmospheric temperatures does, like the surface record, show warming over the longer period while, like the satellite record, showing cooling over the shorter period.

There are a number of reasons to expect the satellite record to be different from the surface record, including stratospheric ozone depletion. The satellite record, while covering the whole globe, is not a measure of surface temperature, but of the temperature of the atmosphere, integrated from 5,000 to 30,000 feet. Since we live at the surface level, the land-based measurements provide a more useful indicator of the temperature changes that are affecting ecosystems and human society.

Further information:

In 1979, researchers added measurements from satellite-mounted Microwave Sounding Units (MSUs) to their arsenal of global climate monitoring systems. Instead of measuring the surface temperature, these satellite instruments measure the temperature of the earth's atmosphere on a global scale. Specifically, the MSUs on the satellites are being used to calculate temperatures in two atmospheric layers: the lower troposphere, from 1-7 km above ground (or ~5,000 to 30,000 feet), and the lower stratosphere, which is between 17 and 21 km above ground. These layers of the atmosphere and the earth's surface differ in their patterns of temperature variation.

This record is expected to differ from the surface temperature record for several reasons. For example, over continental regions, the surface temperature shows greater variation in response to warming from solar energy than does the thick layer of air above the land; in contrast, the sea-surface temperature shows even less temperature variability because of the oceans' great thermal inertia.

Relatively short-term, major events such as the volcanic eruptions of Mt. Pinatubo (1991) and El Chicon (1982), as well as the oceanic temperature changes during El Niño events, explain over 60% of the monthly variation in the MSU tropospheric temperature record. Additionally, air pollutants such as aerosols tend to cool the surface and lower troposphere. Without these "cooling" effects, the global temperature record (as measured by the MSU instruments) has risen over the last 19 years by +0.06 C/decade, while GCM's have predicted a warming rate of +0.08 to +0.30 C/decade over the last few decades. The surface record shows more than 0.1 degree C per decade warming over this same period.

Q5.2 What type of research is U.S. Global Change Research Program conducting to resolve this discrepancy?

A5.2 The USGCRP supports a wide range of activities relating to detection of climate change and identifying human components. These activities include support of satellite observations, including the work by Spencer and Christy with the Microwave Sounding Unit (MSU) instrument record. The USGCRP also supports the creation of temperature records from surface-based sources, such as the work by Jim Hansen and his colleagues at the Goddard Institute for Space Studies (GISS), and work to reconstruct very long-term historical records of the Earth's climate. In addition, the program supports numerous analyses and modeling efforts by teams seeking to resolve apparent inconsistencies, as well as many other activities that contribute to the overall understanding of the Earth system and how it works.

The results from all these efforts are regularly published in the peer-reviewed literature, discussed at scientific meetings, and used as the basis for the definition of new projects and programs to help us narrow the uncertainty of measurements and predictions and increases our understanding of the climate system. This includes major efforts by NASA to develop and deploy improved, more accurate instruments for measuring various aspects of climate change, including temperatures, from space. As is true of all science, the USGCRP welcomes careful analyses that start from a skeptical perspective and test and reexamine all findings. Just as the satellite data may raise questions about some types of findings, other findings raise questions about the satellite data. Working through all of this is part of the intense self-scrutinizing process that science demands.

Q6. The land-based temperature record is subject to the effects of urbanization that could raise temperatures. Because of this bias, some scientists have questioned the appropriateness of using the land-based temperature record alone to detect global warming. Because the satellites measure temperatures three-dimensionally (i.e., between 5,000 and 30,000 feet), there is no bias from urbanization or other factors. Moreover, the satellites cover the entire globe whereas ground-based thermometers do not. How reliable, then, is the ground-based temperature record?

A6. The ground-based temperature record is very reliable. The question you raise about urbanization and the heat-island effect has been carefully and methodically addressed by scientists. The potential impact of the placement of thermometers has been systematically reviewed and adjusted for the influence of urban heat islands. Some of our nation's most prominent researchers have participated in these exercises. See, for example, the recently published paper by Easterling, et al. from *Science* 277:364-367, July 18, 1997, copy attached.

(1994)] showed a large-scale anticyclonic gyre in the general vicinity of the gyre shown in Fig. 1C. However, Reid's gyre and the one depicted in Fig 1C have substantial differences in their vertical structure and horizontal substructure.
7. Southward flow of North Atlantic Deep Water on the eastern side of the Mid-Atlantic Ridge is supported by P. M. Saunders [*J. Mar. Res.* **40**, 641 (1982)], S. Gana and C. Provost [*J. Mar. Syst.* **4**, 67 (1993)], and J. Paillet and H. Mercier (*Deep-Sea Res., Part I*, in press).
8. Topographic sill depths of ~1000 m are a barrier for flow of this density into the Nordic Seas.
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31. I thank J. Pedlosky for his aid in the interpretation of these fields and P. Rhines for his comments on the manuscript. Support from NSF (grant OCE-9629489) is gratefully acknowledged.

20 February 1997; accepted 22 May 1997

Maximum and Minimum Temperature Trends for the Globe

David R. Easterling,* Briony Horton, Philip D. Jones, Thomas C. Peterson, Thomas R. Karl, David E. Parker, M. James Salinger, Vyacheslav Razuvayev, Neil Plummer, Paul Jamason, Christopher K. Folland

Analysis of the global mean surface air temperature has shown that its increase is due, at least in part, to differential changes in daily maximum and minimum temperatures, resulting in a narrowing of the diurnal temperature range (DTR). The analysis, using station metadata and improved areal coverage for much of the Southern Hemisphere landmass, indicates that the DTR is continuing to decrease in most parts of the world, that urban effects on globally and hemispherically averaged time series are negligible, and that circulation variations in parts of the Northern Hemisphere appear to be related to the DTR. Atmospheric aerosol loading in the Southern Hemisphere is much less than that in the Northern Hemisphere, suggesting that there are likely a number of factors, such as increases in cloudiness, contributing to the decreases in DTR.

The global mean surface air temperature has risen about 0.5°C during the 20th century (*1*). Analysis has shown that this rise has resulted, in part, from the daily minimum temperature increasing at a faster rate or decreasing at a slower rate than the daily maximum, resulting in a decrease in the DTR for many parts of the world (*2, 3*). Decreases in the DTR were first identified in the United States, where large-area trends show that maximum temperatures have remained constant or have increased only slightly, whereas minimum temperatures have increased at a faster rate (*4*). Similar changes have been found for other parts of the world as data have become available, allowing more global analyses (*2, 3*). However, in some areas the pattern has been different: In parts of New Zealand (*5*) and alpine regions of central Europe (*6*), maximum and minimum temperature have increased at similar rates, and in India, the DTR has increased as a result of a decrease in the minimum temperature (*7*). To evaluate these varying results, we conducted an expanded analysis on global and regional scales.

Local effects such as urban growth, irrigation, desertification, and variations in local land use can all affect the DTR (*3*); in particular, urbanized areas often show a narrower DTR than nearby rural areas (*8*). Large-scale climatic effects on the DTR include increases in cloud cover, surface evaporative cooling from precipitation, greenhouse gases, and tropospheric aerosols (*9, 10*). Recent studies have demonstrated a strong relation between trends of the DTR and decreases in pan evaporation over the former Soviet Union and the United States (*11*), suggesting that the DTR decrease in these areas is influenced by increases of cloud amount and reduced insolation (*1*). Furthermore, recent modeling studies have suggested that the decrease in the DTR may be a result of a combination of direct absorption of infrared portions of incoming solar radiation, aerosols, and water-vapor feedbacks, including surface evaporative effects (*12*).

We analyzed monthly averaged maximum and minimum temperatures and the DTR at 5400 observing stations around the world. Each time series from each station was subjected independently to homogeneity analyses and adjustments according to recently developed techniques (*13*). In general, these homogeneity adjustments have little effect on large-area averages (global or hemispheric), but they can have a noticeable effect on smaller regions (*14*), particularly when comparing trends at individual or adjacent grid boxes.

Our data covers 54% of the total global land area, 17% more than in previous studies (*3*). Most of the increases are in the Southern Hemisphere, with the addition of data for South America, New Zealand, all of Australia, a number of Pacific islands, and Indonesia. Data were also in-

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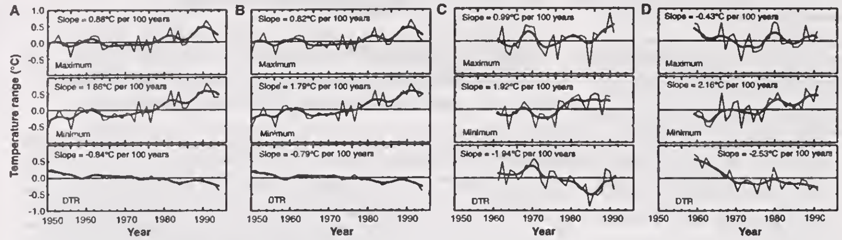


Fig. 1. Time series of annual average maximum temperature, minimum temperature, and DTR for (**A**) the globe, using all available stations, (**B**) the globe, using only nonurban stations, (**C**) Chile and Argentina, using only nonurban stations, and (**D**) Southeast Asia, using only nonurban stations. The heavy line is the result of smoothing with a nine-point binomial filter with reflected ends. Trends (slopes) for the maximum temperatures in (C) and (D) are not statistically significant at the 0.05 level (two-tailed *t* test).

cluded for tropical and subtropical areas, such as the Caribbean, parts of Africa, Iran, Pakistan, and Southeast Asia. However, there are still large parts of the world that remain unanalyzed because of a lack of data, particularly in the tropics, and updating these data remains a problem, as shown by our analysis ending in 1993 (*15*).

In our analysis, we first calculated anomalies from the mean of the base period of 1961 to 1985 for all stations in each 5° by 5° latitude-longitude grid box. The global or hemispheric value for each year was then determined by area-weighting each grid box and averaging all the weighted grid-box values. The overall global trend for the maximum temperature is +0.88°C per 100 years, which is consistent with an earlier finding (*3*). However, the trend for the minimum temperature is +1.86°C per 100 years, which is considerably less than that found in previous analyses. This reduction in the trend for minimum temperature results in a smaller trend in the DTR of −0.84°C per 100 years. This finding is not surprising, because most of the data added here are for tropical and subtropical regions, where temperature changes are not expected to be as large as in regions of higher latitude (*1*), and because of the effects of the Mount Pinatubo eruption. The temperature increases for these 25 years are greater than those over the rest of the 20th century, reflecting the stronger warming during the latter half of this century (*1*).

We examined urban effects on global and hemispheric trends using a metadata set developed at the U.S. National Climatic Data Center. These data indicate whether a station is in an urban or nonurban environment, where urban is defined as a city of 50,000 or greater population (*16*). Approximately 1300 of the original 5400 stations were determined to be urban by this rough measure. The globally averaged time series for the annual maximum and minimum temperature and DTR calculated using only nonurban stations show only slight differences from those calculated using all available stations (Fig. 1). The trend for the maximum temperature excluding the effects of large urban areas is +0.82°C per 100 years, and for the minimum temperature is +1.79°C per 100 years; the DTR trend is −0.79°C per 100 years. The difference in the trends for the maximum and minimum temperatures is about 0.1°C per 100 years, which is consistent with other estimated urban effects on global mean temperature time series (*16*, *17*). The likely effects of the Mount Pinatubo eruption are seen in both the maximum and minimum temperature time series, which show a distinct drop in 1992. The maximum temperature continued to drop in 1993, whereas the minimum stabilized, which resulted in a continued decrease in the DTR.

Maximum temperatures have increased over most areas with the notable exception of eastern Canada, the southern United States, portions of eastern Europe, southern China, and parts of southern South America (Fig. 2). The minimum temperatures, however, increased almost everywhere except eastern Canada and small areas of eastern Europe and the Middle East. The DTR decreased in most areas, except over middle Canada and parts of southern Africa, southwest Asia, Eu-

Table 1. Annual and seasonal trends from 1950 to 1993 for maximum temperature, minimum temperature, and DTR for the globe and the Northern and Southern hemispheres. Trends calculated using only nonurban stations are given, with the trends using all stations given in parentheses.

Season	Trend (°C per 100 years)		
	Maximum temp.	Minimum temp.	DTR
		Global	
D-J-F	1.10 (1.31)	2.48 (2.76)	−1.35 (−1.37)
M-A-M	1.25 (1.17)	2.26 (2.27)	−1.04 (−1.09)
J-J-A	0.47 (0.40*)	1.13 (1.12)	−0.65 (−0.69)
S-O-N	0.05* (−0.01*)	0.94 (0.98)	−0.89 (−0.92)
		Northern Hemisphere	
D-J-F	1.26 (1.52)	2.74 (3.04)	−1.44 (−1.48)
M-A-M	1.39 (1.29)	2.28 (2.30)	−0.90 (−1.01)
J-J-A	0.25* (0.25*)	1.05 (1.04)	−0.79 (−0.77)
S-O-N	−0.12* (−0.01*)	0.72* (0.83)	−0.84 (−0.90)
Annual	0.77 (0.87)	1.74 (1.84)	−0.89 (−0.89)
		Southern Hemisphere	
D-J-F	0.66 (0.62)	1.61 (1.66)	−1.00 (−0.93)
M-A-M	0.59* (0.55*)	1.98 (1.97)	−1.37 (−1.31)
J-J-A	1.27 (1.18)	1.41 (1.40)	−0.08* (−0.12*)
S-O-N	0.69* (0.84)	1.74 (1.69)	−1.08 (−1.02)
Annual	0.91 (0.84)	1.81 (1.80)	−0.59 (−0.60)

*Not significant at the 0.05 level (two-tailed *t* test).

rope, interior Australia, and the western tropical Pacific islands. It should be kept in mind that each grid-box value is the average of 1 to 20 or more stations within that grid box, and that the value for any one grid box is subject to any problems inherent in the station data. Because the DTR is the maximum temperature minus the minimum temperature, the DTR can decrease when the trend in the maximum or minimum temperature is down, up, or unchanging. This relation contributes to the appearance of less spatial coherence on the DTR map than on the other two. Seasonally, the strongest changes in the DTR were in the boreal winter season, and the smallest changes were during the boreal summer (Table 1), suggesting that there is an element of a seasonal cycle in the changes.

Maximum temperatures in southern South America and in Southeast Asia (Fig. 1), two areas not previously analyzed, did not change significantly, although the data for Southeast Asia suggest that temperatures there decreased slightly. In both regions, minimum temperatures increased significantly, resulting in a significant decrease in DTR. Furthermore, minimum temperatures in the Southern Hemisphere increased, and because the tropospheric aerosol load in this hemisphere is much less than that in the Northern Hemisphere, additional factors, such as increases in cloudiness (9), are likely contributing to observed increases in nighttime temperature. The minimum temperature for both areas increased abruptly in the late 1970s, which is also evident in the global time series and coincides with what has been described as a fundamental shift in the El Niño–Southern Oscillation phenomenon (1). Mean annual temperatures

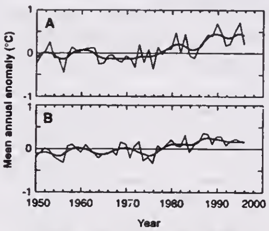
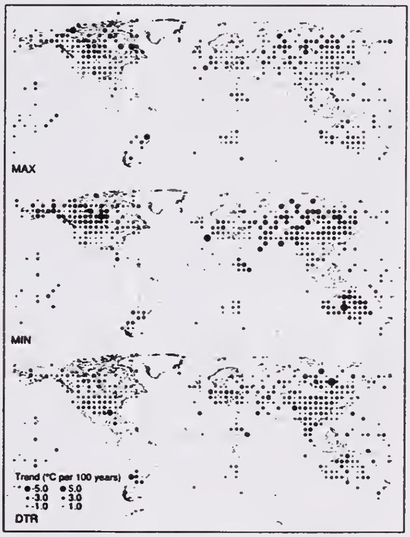


Fig. 3. Mean annual temperature anomalies (from the 1961–90 mean) for the (**A**) Northern Hemisphere and (**B**) Southern Hemisphere.

for the Northern and Southern hemispheres (Fig. 3) show the same abrupt increase in the late 1970s and the effect of the Mount Pinatubo eruption in 1992 (18). However, the temperatures for both hemispheres show a recovery to warmer temperatures, such that 1995 was the warmest year since 1950. Because maximum and minimum temperature changes are reflected in the mean, it is likely that the maximum and minimum temperature and DTR changes presented here continued to occur through 1995.

Circulation changes during the Northern Hemisphere winter were examined for a relation to the winter DTR. A westerly index (WI) was calculated from the cold ocean–warm land (COWL) pattern (19) and regressed against the DTR. Using yearly values, we found the correlation between the WI and DTR over the region 60°W to 90°E, 30°N to 80°N to be −0.37, significant at the 95% confidence level. There is a bipolar pattern in the relation, with positive correlations occurring over the Iberian peninsula, and negative correlations over northern Europe and into Russia. This pattern suggests that strong westerly flow is associated with increased DTR over the Iberian peninsula and decreased DTR over northern Europe and into Russia. The recent increase in WI values over the area is consistent with the observed decreasing DTR.

Fig. 2. Trends (in degrees Celsius per 100 years) for each 5° by 5° latitude-longitude grid box using only nonurban stations for annual maximum temperature, annual minimum temperature, and diurnal temperature range.



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3 March 1997; accepted 2 May 1997

Precursor-Directed Biosynthesis of Erythromycin Analogs by an Engineered Polyketide Synthase

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A genetic block was introduced in the first condensation step of the polyketide biosynthetic pathway that leads to the formation of 6-deoxyerythronolide B (6-dEB), the macrocyclic precursor of erythromycin. Exogenous addition of designed synthetic molecules to small-scale cultures of this null mutant resulted in highly selective multimilligram production of unnatural polyketides, including aromatic and ring-expanded variants of 6-dEB. Unexpected incorporation patterns were observed, illustrating the catalytic versatility of modular polyketide synthases. Further processing of some of these scaffolds by postpolyketide enzymes of the erythromycin pathway resulted in the generation of novel antibacterials with in vitro potency comparable to that of their natural counterparts.

Polyketides comprise a large and diverse group of natural products, many of which possess important biological and medicinal properties (*1*), yet polyketide biosynthesis proceeds by simple, repetitive condensations of acetate or propionate monomers in a manner that closely parallels fatty acid synthesis (*2*). Structural complexity is introduced by variation in the stereochemistry and the degree of reduction after each condensation as well as by downstream enzymes that catalyze cyclizations, oxidations, alkylations, glycosylations, and other transformations. Although these compounds are an attractive target for drug discovery (*1*), the complexity of many interesting polyketides impedes the preparation of analogs. Genetic methods for manipulating polyketide synthases (PKSs) show considerable promise for the engineered biosynthesis of novel polyketide molecules (*3*) but are currently limited in the range of compounds that may be accessed. The challenges involved in total synthesis of macrolides (*4*) make this approach impractical for the preparation of derivatives. Synthetic modification of macrolides has led to the preparation of interesting compounds (*5–7*), but this method can also be extremely labor intensive and is limited in the range of transformations that can be selectively performed on these complex natural products. We report the development of a generally applicable, fermentation-based strategy in which chemically synthesized, cell-permeable, non-natural precursors are transformed into molecules resembling natural products by genetically engineered PKSs.

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Deoxyerythronolide B synthase (DEBS) produces 6-deoxyerythronolide B (6-dEB) (**1** in Fig. 1), the parent macrolactone of the broad-spectrum antibiotic erythromycin. DEBS consists of three large polypeptides (each >300 kD), each containing ~10 distinct active sites. A one-to-one correspondence between active sites and chemical steps has been proposed (*8*, *9*), leading to a model for the synthesis of 6-dEB in which each elongation step is handled by a separate enzyme "module" [see figure 1 of (*10*)]. The modular nature of DEBS and related PKSs (*11*) suggests potential strategies for genetic manipulation to generate novel natural products. Indeed, the feasibility of generating new polyketides has been demonstrated through the use of module deletion (*12*), loss-of-function mutagenesis within reductive domains (*9*, *13*, *14*), replacement of acyltransferase domains in order to alter starter or extender unit specificity (*15*), and gain-of-function mutagenesis to introduce novel catalytic activities within modules (*16*). Importantly, many experiments show that downstream enzymes can process non-natural intermediates.

Biochemical analysis has also revealed that DEBS has considerable tolerance toward non-natural substrates. For example, primer units such as acetyl and butyryl coenzyme A (CoA) (*17*), or *N*-acetylcysteamine (NAC) thioesters of their corresponding diketides (*18*), can be incorporated in vitro into the corresponding analogs of 6-dEB. However, in the course of these studies, it became clear that, even in the absence of externally added propionyl primers, a potential non-natural substrate must compete with propionate primers derived in situ by means of enzyme-catalyzed decarboxylation of methylmalonyl extender units (*19*). This competition puts severe limits on the priming of DEBS with unnatural thioesters because, for a poorly incorporated substrate, 6-dEB would be expected to be the dominant product.

We focused on incorporating substrates in vivo as cell-permeable NAC thioesters. Although exogenously fed NAC thioesters of advanced intermediates incorporate into several natural products derived from modular PKSs, the degree of specific incorporation was low (<3%) in all cases, presumably because of competing synthesis from metabolically derived intermediates (*20–23*). Mutational biosynthesis (*24*) offers the advantage of eliminating such competition. For example, a randomly generated mutant strain of the avermectin producer, in which biosynthesis of branched primer units is blocked, has been used to generate avermectin derivatives of commercial utility (*21*, *25*). However, the unpredictability of random mutagenesis, coupled with the observation that incorporation efficiencies of natural and non-natural substrates by such a mutant are low (*26*), precludes the general applicability of this strategy. In contrast, the specific introduction of null mutations, facilitated by the modular nature of DEBS, provides a general method for construction of useful blocked mutants. For example, inactivation of the ketosynthase KS1 would be expected to abolish normal biosynthesis, but polyketide production might still occur if an appropriate diketide (such as **2** in Fig. 1) was supplied as an NAC thioester. This has been demonstrated in the case of an engineered bimodular derivative of DEBS (*27*). To evaluate the utility of such a mutational strategy for practical precursor-directed biosynthesis of novel, structurally complex molecules, we introduced the same KS1 null mutation in the context of the full DEBS system.

<u>Evidence for Significant Regional Ecosystem Response to Warming Experienced during the Period 1981-1991</u>

Q7. **Your testimony refers a paper published in the April 17, 1997 issue of *Nature* that "presented compelling evidence for significant regional ecosystem response to warming experienced during the period 1981-1991."**

Please provide a copy of that paper for the record.

A7. Attached is a copy of the paper "Increased plant growth in the northern high latitudes from 1981 to 1991," by R. B. Myneni, C.D. Keeling, C. J. Tucker, G. Asrar, and R. R. Nemani. The paper was published in Volume 386 of *Nature*.

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Increased plant growth in the northern high latitudes from 1981 to 1991

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Variations in the amplitude and timing of the seasonal cycle of atmospheric CO_2 have shown an association with surface air temperature consistent with the hypothesis that warmer temperatures have promoted increases in plant growth during summer[1] and/or plant respiration during winter[2] in the northern high latitudes. Here we present evidence from satellite data that the photosynthetic activity of terrestrial vegetation increased from 1981 to 1991 in a manner that is suggestive of an increase in plant growth associated with a lengthening of the active growing season. The regions exhibiting the greatest increase lie between 45° N and 70° N, where marked warming has occurred in the spring time[3] due to an early disappearance of snow[4]. The satellite data are concordant with an increase in the amplitude of the seasonal cycle of atmospheric carbon dioxide exceeding 20% since the early 1970s, and an advance of up to seven days in the timing of the drawdown of CO_2 in spring and early summer[1]. Thus, both the satellite data and the CO_2 record indicate that the global carbon cycle has responded to interannual fluctuations in surface air temperature which, although small at the global scale, are regionally highly significant.

We have made use of data from the advanced Very High Resolution Radiometers (AVHRRs) on board the National Oceanic and Atmospheric Administration (NOAA) series of meteorological satellites (NOAA-7, -9 and -11). From daily observations of channel 1 (wavelengths ~0.58–0.68 μm) and channel 2 (~0.72–1.1 μm) reflectances, global land data sets of normalized difference vegetation index (NDVI) were produced[5,6]. The NDVI is expressed on a scale from −1 to +1. It is between −0.2 and 0.05 for snow, inland water bodies, deserts and exposed soils, and increases from about 0.05 to 0.7 for progressively increasing amounts of green vegetation[7]. NDVI data are strongly correlated with the fraction of photosynthetically active radiation (wavelength 0.4–0.7 μm) absorbed by vegetation[8], that is, to the photosynthetic activity of vegetation canopies[9]. Two global data sets of NDVI were analysed: (1) the land segment of the joint NOAA/NASA Earth Observing System AVHRR Pathfinder data set at 8 km spatial resolution and 10-day intervals, for the period July 1981 until the end of June 1991[6], and (2) the Global Inventory Monitoring and Modelling Studies

(GIMMS) AVHRR NDVI data set at a similar spatial resolution, but at 15-day intervals, for the period January 1982 until the end of December 1990[10]. The Pathfinder data were calibrated to correct for post-launch degradation from estimates of the relative annual degradation rates (in %) of the two channels: 3.6 and 4.3 (NOAA-7), 5.9 and 3.5 (NOAA-9) and 1.2 and 2.0 (NOAA-11)[11]. NOAA-9 data were used for inter-satellite normalization. The GIMMS data were independently calibrated[12]; they are considered here to illustrate how a different calibrating scheme affects derived trends in the AVHRR data.

For each equal-area pixel and at either 10- or 15-day intervals, depending on which of the two satellite data sets was used, the maximum of NDVI with minimal atmospheric effects was retained[13]. The NDVI data from high northern latitudes (>40° N) did not show anomalies related to the El Chichon volcanic eruption during the mid-1982 to 1983 time period. These effects in the low latitude data were not corrected for in either of the two satellite data sets.

The calibrated Pathfinder NDVI data still showed residual non-vegetation-related variations[14]. We revised them by adjusting the NDVI for a hyper-arid portion of the Sahara desert (1.42×10^6 km^2) which has been found to be invariant as viewed by all three satellites[10]. An alternate correction scheme based on desert pixels from 10° N to 50° N yielded nearly identical results. Importantly, when this desert correction was applied to the NDVI anomaly time series of desert pixels from five-degree latitude bands between 10° N and 50° N, the residuals resembled noise.

Time series of spatially averaged monthly NDVI, evaluated as the mean of three 10-day maximum value NDVI composites, comprising a 10-year record, are plotted, first directly for reference (Fig. 1a), and then as anomalies to display interannual variability (Fig. 1b). Averaged for regions north of 45° N (uppermost curve in Fig. 1b) the NDVI anomaly shows evidence of increasing amplitude, summer values being low early in the record, high near the end. The NDVI anomaly in the tropics shows a large increase starting from November 1988, which also coincided with the change in satellites from NOAA-9 to NOAA-11. A somewhat smaller increase is seen during the switch from NOAA-7 to NOAA-9 in January 1985, although this increase began in the last months of the NOAA-7 record (and the anomaly north of 45° N actually shows a decrease). This raises a question regarding anomalous variations in NDVI from sensor changes. Although efforts have been made to establish

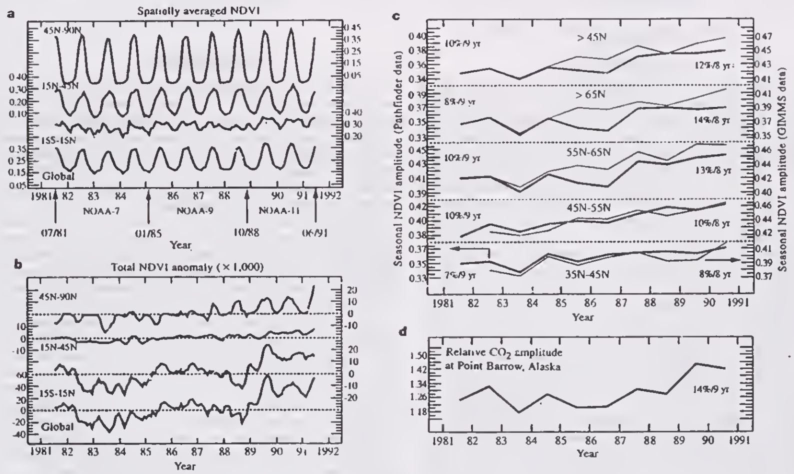

Figure 1 Time variations in normalized difference vegetation index (NDVI) compared with changes in amplitude of the seasonal cycle of atmospheric CO_2 for the period from July 1981 to the end of June 1991. The data in **a** and **b** have been smoothed by a 3-month running mean. Zonal total NDVI and its anomaly were calculated from pixels having a 10-year monthly average NDVI greater than 0.1 and within 3σ of the monthly average. The first condition guaranteed that bare or sparsely vegetated pixels were not included in spatial averages, while the second condition removed most of the influence of snow and bad scan-lines. **a**, Monthly average NDVI for selected latitudinal bands and the whole globe. The zonal total NDVI was normalized by the total vegetated land area in the month of August to obtain a zonal average that exhibited seasonality[14]. **b**, Monthly total anomalies of the above, expressed as departures from the 10-year record averages of monthly NDVI, summed over each latitudinal band[14] for each month. The vertical scale of the global plot is twice that of individual latitudinal bands. **c**, Seasonal amplitude of NDVI averaged over selected latitudinal bands. The amplitude, defined as the July and August average, is a good approximation because, at the northern latitudes shown, the winter-time NDVI value is close to zero. Spatial averaging was for July and August data combined over pixels with 10-year averages of NDVI greater than 0.1, in order to exclude bare areas, such as the great deserts of Asia. Results from both the Pathfinder (left ordinate) and GIMMS (right ordinate) NDVI data sets are shown together with the corresponding rates of increase. The higher rates of increase inferred from GIMMS data may be due to the lack of desert correction for the version of GIMMS data used in this analysis. **d**, Seasonal amplitude of atmospheric CO_2 relative to a base-period of 1961–67 as registered at Point Barrow, Alaska (71° N, 157° W)[1]. Linear trend estimates of the increase in seasonal amplitudes of NDVI and CO_2 are statistically significant (10% level) for all latitudinal bands shown. However, the limitations of regression analysis on short samples, that is, the determination of trend in the presence of low-frequency variations, must be noted

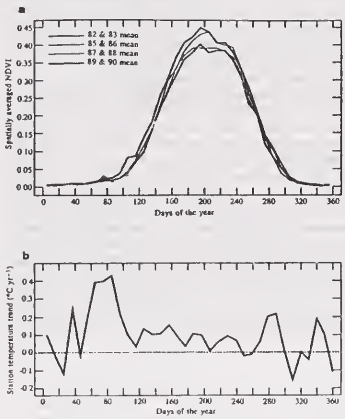

Figure 2 Interannual changes in seasonality of NDVI and in surface temperature, averaged north of 45° N, for selected pairs of years from 1982 to the end of 1990. **a**, NDVI averaged from 10-day maxima in NDVI for 1982-3, 1985-6, 1987-8 and 1989-90. Data from 1984 were not included because the number of years was odd. Spatial averaging was similar to that described in Fig. 1a legend. Changes in the timing of the active growing season over this 9-year record period were estimated from differences between the first and last bi-yearly average profiles at six threshold values of NDVI (from 0.1 to 0.35 in 0.05 increments). These values occurred during intervals of about 60 days each in spring and autumn when, respectively, NDVI was increasing and decreasing, at almost a constant rate. The six estimates each of the timing of rise and fall of NDVI may actually be correlated because of low-frequency variations (for example, soil moisture and/or equatorial sea surface temperature oscillations), and therefore, the standard errors given in the text must be interpreted in light of this limitation. We also inferred similar changes in the active growing season duration from an alternate pixel-by-pixel and year-by-year analysis[14]. **b**, Changes in the annual cycle of near-surface air temperature from 1982 to 1990. Daily thermometer observations of maximum and minimum temperature were averaged in order to approximate daily mean temperatures and interpolated on a 1 × 1 degree grid[22]. The daily data were further averaged over three separate approximately 10-day periods per month to obtain 36 observations per year. These 10-day average temperatures were then linearly regressed on the year (from 1982 to the end of 1990) to obtain the slopes shown here.

proper inter-sensor calibration linkages[11,12], some residual effects cannot be ruled out, especially between NOAA-9 and NOAA-11[14]. This situation, for example, confounds proper interpretation of the tropical NDVI anomaly time series. For instance, intense sea surface temperature (SST) oscillatory events in the tropical Pacific and Atlantic oceans from 1982 to early 1989 have been linked to decreased vegetation growth in large regions of the semi-arid tropics[15]. The increase in tropical and global NDVI anomaly starting from late 1988 also coincided with an unprecedented decline in atmospheric CO_2 anomaly, from a peak value in late 1988 to a minimum in late 1993[16]. Nevertheless, these interpretations, as they involve the NDVI data, are limited by possible sensor change effects.

Changes in the amplitude of the seasonal cycle of NDVI at northerly latitudes greater than 35°N are plotted in Fig. 1c, as characterized by changes in the July and August average NDVI. This broad measure of the seasonal maximum approximates the seasonal amplitude because winter-time NDVI at these northern latitudes is close to zero (compare Fig. 1a). The seasonal amplitude, by this definition, increased by 7 to 14%, depending on the latitude and data set, from 1981 or 1982 to the end of 1990 (Fig. 1c). Because NDVI is a measure of photosynthetic activity of vegetation as noted above[8,9], this increase indicates a substantial change in photosynthetic activity of plants at higher northern latitudes. A similar increase (14%) is indicated in the amplitude of the seasonal cycle of atmospheric CO_2 measured at Point Barrow, Alaska[1] (Fig. 1d). This CO_2 cycle, although observed in the Arctic (71°N), registers changes in CO_2 gas exchanges, and hence in the biotic activity of plants and soil over all northern temperate and polar latitudes[17]. Together, the NDVI and CO_2 data indicate increased biospheric activity north of about 35°N. Two recent studies have also reported increased photosynthetic activity in the northern high latitudes as increased biomass from deposition in European forests[18] and from tree-ring analysis in Mongolia[19], respectively.

Timing of the seasonal rise and fall in NDVI suggests possible changes in the length of the active growing season, that is, the period during which photosynthesis actually occurs (as opposed to the concept of growing season, measured for example in degree days. As shown in Fig. 2a in Pathfinder data, the rise in NDVI, spatially averaged from 45°N to the northern limit of the data, came progressively earlier in the season between 1982 and 1990, as shown by successive 10-day averages, where each plot shows an average over two years for clarity. Because spatially averaged NDVI rose each year at nearly a constant rate from early April (about day 110) to late June (about day 170) the advance in the active growing season is apparent, notwithstanding the relatively coarse time resolution (10 day) afforded by the NDVI data. From six estimates of the time advance at six successive thresholds of NDVI, we estimate an advance of 8 ± 3 days (Fig. 2a).

An advance of about 7 days in the seasonal cycle was previously inferred from atmospheric CO_2 data as having taken place between the 1960s and early 1990s, with most of the increase occurring after 1980 (Fig. 1 of ref. 1). The NDVI data suggest that this increase occurred over an extensive region of the extratropical Northern Hemisphere. The NDVI data in Fig. 2a further indicate a prolongation of the declining phase of the active growing season, estimated at 4 ± 2 days between 1982–3 and 1989–90. Therefore, the active growing season north of 45° N appears to have lengthened by 12 ± 4 days over the 1980s. These estimates must be interpreted as suggestive of a longer active growing season, rather than in an absolute sense, in view of the coarse temporal resolution (10 days) and residual atmospheric effects in NDVI data. The associated standard errors given here are not rigorous, for low-frequency variations in NDVI data invalidate the assumption of statistical independence required of the successive threshold values.

Variations in the amplitude and timing of the seasonal cycle of atmospheric CO_2 have shown an association with surface air temperature consistent with the hypothesis that warmer temperatures have promoted increases in biospheric activity outside the tropics[1,2]. A likely cause is an increase in the length of the active growing season brought about by warmer temperatures[1]. As shown in Fig. 2b, a pronounced increase in late-winter and early-spring temperatures took place over the period of NDVI changes, especially during March.

Because of their high spatial resolution (relative to ground-based meteorological measurements), NDVI data provide spatial detail of where the average changes in amplitude and timing of the active growing season occurred. To address regional variations in NDVI, we show in Fig. 3 a map related to the time plots shown in Fig. 1 together with a map of the 9-year average of NDVI for comparison.

The linear rate of change in NDVI, averaged over the 9 years of

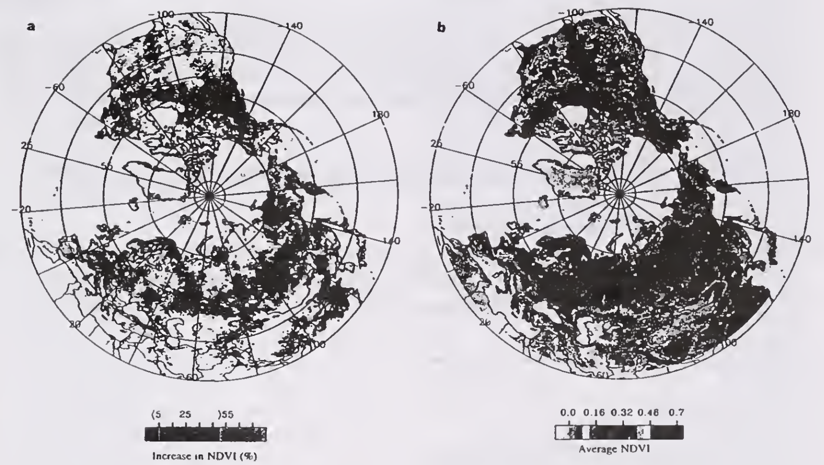

Figure 3 Geographical distribution of the change from 1982 to 1990 in NDVI of land areas north of 27.75° N, expressed as the average over the northern active growing season of May to the end of September. **a**, NDVI increase in percentage over 9 years, determined by linear regression of year-to-year northern growing season averaged NDVI, aggregated to 0.25 × 0.25 degree pixels from original 8-km-resolution data. Only estimates with a positive slope and a statistically significant (10% level) regression coefficient were contoured. There were no pixels with statistically significant negative slopes. Again, we emphasize the limitations of regression analysis on short-term samples. **b**, Nine-year average NDVI over northern active growing season of May to the end of September determined by averaging the monthly NDVI of 0.25 × 0.25 degree pixels from 1982 to 1990.

seasonal NDVI data in northern latitudes, from 1982 to the end of 1990, are mapped in Fig. 3a. Data were averaged from May to the end of September, to approximate the main active growing season of land vegetation in the Northern Hemisphere.

In Eurasia, a band of increasing NDVI extends from Spain in a northeasterly direction across Asia to the western Pacific Ocean. In this band, central Europe, southern Russia, and a broad region near Lake Baikal in Siberia are most affected. Outside this band, northern Scandinavia, northern China, and northeastern Siberia are also strongly affected. In North America, a band of increasing NDVI extends from Alaska in a southeasterly direction to the Great Lakes, thence northeasterly to Labrador. In this band, northwestern Canada is most strongly affected. Outside this band, the continental United States (excluding Alaska) and the area around the Hudson Bay show little change in NDVI.

In general, the regions of greatest increase in NDVI are inland from the oceans, except in the Arctic, and are north of 50° N. The prominent bands of increased NDVI referred to above in both Eurasia and North America, correspond generally to areas of high NDVI (Fig. 3b). Thus most of the areas where changes in NDVI amplitude and seasonality were observed are also regions of significant vegetation density. Notable exceptions are several Arctic regions in Eurasia where NDVI rose sharply from low initial values.

We believe the increasing trend in photosynthetic activity of the northern high latitudes, inferred from satellite observations of NDVI amplitude and phase, to be robust despite varying satellite overpass times and the lack of an explicit atmospheric correction. These effects, however, could modify the magnitudes of NDVI amplitude and estimates of the active growing season duration.

Analyses of station temperature trends during 1961–90 indicate pronounced warming over substantial areas in Alaska, northwestern Canada and northern Eurasia[3]. The greatest warming, up to 4 °C, has occurred in winter. Only slightly less warming has occurred in the same regions in spring, but considerably less warming in summer and even less in autumn[3]. Associated with warming at high latitudes is an approximate 10% reduction in annual snow cover from 1973 to the end of 1992, especially an earlier disappearance of snow in spring (Table 1 of ref. 4). Where snow-lines have retreated earlier due to enhanced warming, we expect an early start of the active growing season.

The winter and spring warming in the interior of the continents of Asia and North America in the 1980s may be a result of natural causes not yet explained, but its timing is consistent with an enhanced greenhouse effect caused by build-up of infrared-absorbing gases in the atmosphere[20]. The unusual warming which peaked near 1990 was of global extent. Although it amounted to a departure of only a few tenths of a degree from previous record temperatures[21], it was associated with far greater warming in the spring months at high northern latitudes. Biospheric activity there, based on our analysis, increased remarkably as a result of this warming, suggesting that small changes in global temperature may reflect disproportionate responses at the regional level, and may be accompanied by positive feedbacks which can markedly influence processes such as photosynthesis and litter decomposition. □

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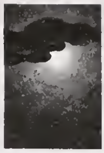
<u>Records of Total Rainfall and Extreme Rainfall for the United States Over the Last Century</u>

Q8. On pages 4 and 5 of your written testimony, you discuss NOAA's Tom Karl review of the records of total rainfall and extreme rainfall for the United States over the last century and conclusions he reached based upon that review.

Please provide a copy Mr. Karl's review and the underlying data used in that review.

A8. Please see the attached article by Tom Karl and Richard Knight, "Secular Trends of Precipitation Amount, Frequency, and Intensity in the United States," which was recently published in the Bulletin of the American Meteorological Society.

Secular Trends of Precipitation Amount, Frequency, and Intensity in the United States



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ABSTRACT

Twentieth century trends of precipitation are examined by a variety of methods to more fully describe how precipitation has changed or varied. Since 1910, precipitation has increased by about 10% across the contiguous United States. The increase in precipitation is reflected primarily in the heavy and extreme daily precipitation events. For example, over half (53%) of the total increase of precipitation is due to positive trends in the upper 10 percentiles of the precipitation distribution. These trends are highly significant, both practically and statistically. The increase has arisen for two reasons. First, an increase in the frequency of days with precipitation [6 days (100 yr)$^{-1}$] has occurred for all categories of precipitation amount. Second, for the extremely heavy precipitation events, an increase in the intensity of the events is also significantly contributing (about half) to the precipitation increase. As a result, there is a significant trend in much of the United States of the highest daily year–month precipitation amount, but with no systematic national trend of the median precipitation amount.

These data suggest that the precipitation regimes in the United States are changing disproportionately across the precipitation distribution. The proportion of total precipitation derived from extreme and heavy events is increasing relative to more moderate events. These changes have an impact on the area of the United States affected by a much above-normal (upper 10 percentile) proportion of precipitation derived from very heavy precipitation events, for example, daily precipitation events exceeding 50.8 mm (2 in.).

1. Introduction

In many areas of the United States during recent years, there has been a notable number of catastrophic flooding episodes. A few examples include the 1993 flooding event along the Mississippi, the New England floods during the autumn of 1996, the winter floods of 1997 in the Pacific Northwest and California, and the 1997 spring floods along the Ohio River and the Red River Valley. Previous work (Karl et al. 1996) has documented an increase in the proportion of the area of the United States affected by a much above-normal frequency of extreme precipitation events, for example, > 50.4 mm day^{-1} (or 2 in.). A thorough analysis of how precipitation is changing in the United States, however, has not been provided.

Changes in precipitation have most often been quantified in terms of changes in the total precipitation over long averaging periods, for example, annually, seasonally, and occasionally monthly. Such statistics (Karl et al. 1993; Groisman and Easterling 1994; IPCC 1990, 1996), although quite useful for many applications, do not reveal important aspects of how precipitation changes within such a long averaging period. After all, most precipitation events in the midlatitudes last a few days at most.

It would be remiss not to mention some notable work that has emphasized changes in precipitation intensity (Englehart and Douglas 1985; Diaz 1991; Yu and Neil 1991; Nicholls and Kariko 1992; Karl et al. 1995; R. Suppiah and K. Hennessy 1998, manuscript submitted to *Int. J. Climatol.*; Mearns et al. 1995). In these analyses, however, there has been no standard technique of investigating precipitation intensity. For example, R. Suppiah and K. Hennessy (1998, manuscript

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submitted to *Int. J. Climatol.*) calculate trends equivalent to the number of days with precipitation to understand how the frequency of precipitation contributes to changes of precipitation, but only the trends of the 90th and 95th percentiles of daily precipitation amount are used to calculate how the intensity of precipitation may be affecting the trend. Nicholls and Kariko (1992) define precipitation intensity as the mean rainfall per day, but define a rainfall event as any period of days with consecutive rainfall. Mearns and Giorgi (1995) analyze on a monthly basis the number of precipitation days, the average rainfall per rain day (what they define as intensity), and the average rainfall per day.

Although there is no single method of analysis that can comprehensively cover all the important aspects of how precipitation changes over the course of time, it is fairly apparent that more consideration needs to be given to the type of questions various analyses can address. For example, a rather fundamental question might be related to how much of any precipitation increase or decrease is attributable to changes in the frequency of precipitation versus intensity of precipitation. For example, increased precipitation could be derived from simply more days during the year with precipitation, and they may be equally distributed for all quantiles[1] of daily precipitation amount. Alternatively, one could also envision a situation where the number of days with precipitation does not change, but the amount of precipitation changes for all, or a limited number of quantiles.

2. Data

There are several datasets that are used in this analysis. The primary dataset is the daily precipitation dataset used by Karl et al. (1996). This dataset consists of 182 stations across the contiguous United States. Of these 182 stations, 134 are part of the U.S. Historical Climate Network (HCN, Hughes et al. 1993). An additional 48 stations were added to improve data coverage in the western United States. Detailed station histories for all of these stations indicate that standard 8 in. precipitation gauges have been used throughout the twentieth century at all locations. This dataset is referred to as the HCN special network (HCNs). The data from these stations span the period 1910–96, but there is some missing data, and some stations do not have data back through 1910. To prevent missing data from introducing any bias, Karl et al. (1995) describe a procedure that was used to estimate missing data. Basically, a gamma function is fit to each station's daily data for each month of the year. To determine if precipitation occurs on any missing day, a random number generator is used such that the probability of precipitation is set equal to the empirical probability of precipitation during that month. If precipitation occurs, then the gamma distribution is used to determine the amount that falls for that day, again using a random number generator.

The other two datasets that are included in this study are used primarily to serve as a cross check against the 182 daily dataset. This includes the climatological state divisional precipitation data (Guttman and Quayle 1996), which are monthly averages based on all reporting stations in the United States. In some years and months, this network reaches over 7500 stations. Most of these stations are cooperative weather stations that have not changed in instrumentation during the twentieth century, unlike the first-order stations, which have been affected by new automated instruments and the introduction of wind shields (Karl et al. 1993). These data span the period of the HCNs data, but there is an uneven number of stations that enter and leave the network during the course of the twentieth century, possibly contributing to some bias in trends. The other dataset (TD3200) consists of 3091 stations in the United States that reported daily precipitation and passed our completeness criterion. The period of record is shorter for these data, spanning the years 1948–95, and each station had to have at least 80% of all data present. The TD3200 data were subjected to the standard National Climatic Data Center (NCDC) data checks as given in TD3200 documentation.

3. Methods

a. Spatial averages

The HCNs daily precipitation data as well as the TD3200 data were arithmetically averaged into 1° × 1° grid cells. These grid cells were then area weighted to calculate changes of precipitation for nine regions across the United States. A national average was derived from these nine regions by area weighting the values within each region on a monthly basis. All sea-

[1]The value of any quantile (Q) in a sample is given by the ordered data values themselves. The order of the quantile is given by $P_i = (i - 0.5)\,n^{-1}$, where $i = 1$ to n, and n is the sample size. So $Q(0.5)$ is the median, $Q(0.25)$ is the first quartile, etc.

sonal averages are derived from the totals of each month where the standard seasons apply, for example, winter (December–February), spring (March–May), etc. The CD data were area weighted into regional and subsequently into national averages from 344 divisional averages.

b. Precipitation assessment

Changes in precipitation amount can occur from a change in the frequency of precipitation events, the intensity of precipitation per event, or any combination thereof. Precipitation intensity is defined here simply by the amount of precipitation associated with specific quantiles of the precipitation distribution. Percentiles near 100 represent very intense precipitation and those near zero very light precipitation events. Daily precipitation totals are treated as precipitation events.

It is possible to estimate the proportion of any trend in total precipitation that is attributable to changes in frequency versus changes in precipitation intensity. This is calculated for the frequency component by determining the average precipitation amount per event ($\overline{P}_e$) and the trend in the frequency of events (b_f). Then the change in precipitation due to the trend in the frequency of precipitation events (b_f) is simply defined by

$$b_e = \overline{P}_e(b_f). \quad (1)$$

In this analysis, b_e is expressed as (mm yr^{-1}) or (mm season^{-1}) or as (a % of the mean seasonal or annual total precipitation), for example, (mm day^{-1}) (day yr^{-1}) = mm yr^{-1}. For the intensity component, the trend is directly calculated as a residual using the expression

$$b_i = b - b_e, \quad (2)$$

where b is the trend in total precipitation for the frequency band or intensity component.

For comparative purposes, trends of total precipitation are expressed as a percent of mean precipitation for months, seasons, annually, etc. The full period of record is used in this analysis to calculate the expected mean total precipitation.

Expressions (1) and (2) are insufficient, however, to adequately describe the nature of precipitation variations and change. For example, it would not be possible to know whether the change in precipitation frequency was due to a change in the number of days with very heavy precipitation or light precipitation amounts. Similarly, it would be uncertain as to whether the precipitation intensity had increased across all quantiles of the distribution or just a few, such as the very heavy precipitation intensities or some of the more moderate intensities, for example, around the median.

Information about these kinds of changes can be obtained by simply applying (1) and (2), not to the full dataset, but to specific class intervals defined by the quantiles of the precipitation distribution. In this analysis the precipitation distribution is categorized into 20 class intervals, where each class interval has a width of five percentiles. The percentile defined intervals range from the lowest percentile to the 5th percentile, the 5th to the 10th percentile, . . . and the 95th to the highest percentile. These percentiles were defined for each station on a monthly, seasonal, and annual basis. So, for each season of interest, (1) and (2) is directly applied 20 times to the ensemble of all values falling within each of these class intervals for the time period of interest, that is, 1910–96.

Trends of precipitation can also be calculated for specific quantiles. One particular statistic of interest is the trend of the highest daily precipitation amount. In this analysis, we find the highest and median precipitation amount each month for all years of record and then calculate the trend of these values. The amount of precipitation associated with the trend is expressed as a percentage of the mean of these year-month total precipitation amounts, for example, either the highest monthly daily total or the median of the daily totals.

Another way to analyze how precipitation is changing is to evaluate the trends of the proportion of precipitation falling in a specific class interval compared with the total mean precipitation. This statistic also provides information about relative changes within the distribution unrelated to changes in the mean.

Another aspect of precipitation change that is important in some applications relates to trends in the area affected by heavy or extreme precipitation amounts. In this analysis, the upper 10 percentile is defined as a very heavy precipitation event. Similar to the analysis of Karl et al. (1996), the area of the United States affected by a much greater than normal (upper 10 percentiles) frequency of the proportion of total annual precipitation derived from very heavy precipitation was calculated for each station. The trend in the area affected by these events is calculated on a national and regional basis. In this analysis, the upper 10 percentile has been chosen as the class limit, but obviously other class limits could have been selected.

4. Results

Precipitation has increased across the United States over much of the twentieth century (Table 1). The increase is most pronounced during the spring and autumn but is also apparent during summer. Wintertime precipitation amount has increased only slightly. The sensitivity of the trend to the dataset used is reflected in Table 1. It is apparent that the annual increase in precipitation is fairly stable from one dataset to the next, but for seasonal trends, even when the trends are statistically significant, differences among the datasets can be up to 4% per century. Given the variability of trends between the datasets from TD3200 and CD (Table 1), the use of the higher quality, lower density HCNs is not grossly affected by its relatively low coverage.

TABLE 1. United States national precipitation trends expressed in terms of percent of the mean per century and (top line) millimeters per century (bottom line) in each row. Statistical significance ($\alpha = 0.05$) is reflected by bold numbers based on a nonparametric Kendall τ-test. Datasets are HCNs, Climate Division (CD) data (the U.S. climatological division dataset), and TD3200.

Dataset	Time period	Annual	Winter	Spring	Summer	Autumn
HCNs	1910–96	**10.1**	2.8	**11.2**	**11.6**	**14.3**
		81	5	**23**	**24**	**29**
CD	1910–96	**10.0**	−0.3	**14.3**	6.6	**19.5**
		76	−1	**29**	14	**34**
CD	1901–96	**7.7**	1.1	**9.3**	2.1	**19.2**
		65	2	**19**	4	**40**
TD 3200	1948–95	**16.9**	−7.2	**23.6**	11.8	**37.7**
		128	−12	**48**	25	**66**
HCNs	1948–95	**14.7**	−7.0	20.0	5.5	**40.1**
		110	−12	**41**	11	**71**
CD	1948–95	**19.5**	−2.6	**23.9**	**10.3**	**48.8**
		151	−5	**49**	**21**	**86**

Figure 1 depicts how the change in precipitation has occurred. In such an analysis, it is possible to understand the contribution of light, medium, and heavy precipitation amounts to the total trend. The sum of the trend across all class intervals is identically equal to the trend of the total precipitation. Nationally, on an annual basis, over half of the precipitation increase is due to the increase of precipitation within the upper 10% of all the daily precipitation amounts, for example, class intervals 90 and 95 in Fig. 1a. The trends in these two categories are highly significant based on Kendall's nonparametric τ statistic[2], and Fig. 2 depicts the time series from which the trends were derived. Over half (53%) of the total trend is due to the upper 10% of daily precipitation events, despite the fact that they only constitute about 35% or 40% of the total annual precipitation across the United States. Given this, the trends in these percentiles are larger than might be expected. The contribution to the increase in precipitation due to the heaviest precipitation events is even more pronounced during the summer (Fig. 1), as about half of the increase in summer precipitation is from the highest class interval (> the 95th percentile). During both spring and autumn (Fig. 1 and Table 1), the same tendency is observed, a significantly large contribution to the total trend from the higher percentile class intervals.

Based on Table 1, it might be tempting to conclude that during winter there has been little change in precipitation frequency or intensity, but Fig. 1 indicates that precipitation from the heaviest categories has increased, although not in a statistically significant manner, but this accounts for all of the increase. The lighter precipitation categories have tended to have slight decreasing trends, partially offsetting the increase from the heaviest categories.

The trends in the frequency of events (Fig. 3) within each of the percentile-defined class intervals indicates that at least a portion of the increase in precipitation is due to an increase in the frequency of events. On an annual basis, virtually every region has a statisti-

[2]Kendall's τ statistic for trends tests the nonrandomness of the ranks of the time-dependent data. It is nearly as powerful as Pearson's correlation coefficient in rejecting the hypothesis of no trend in the data, but is insensitive to the distribution of the data.

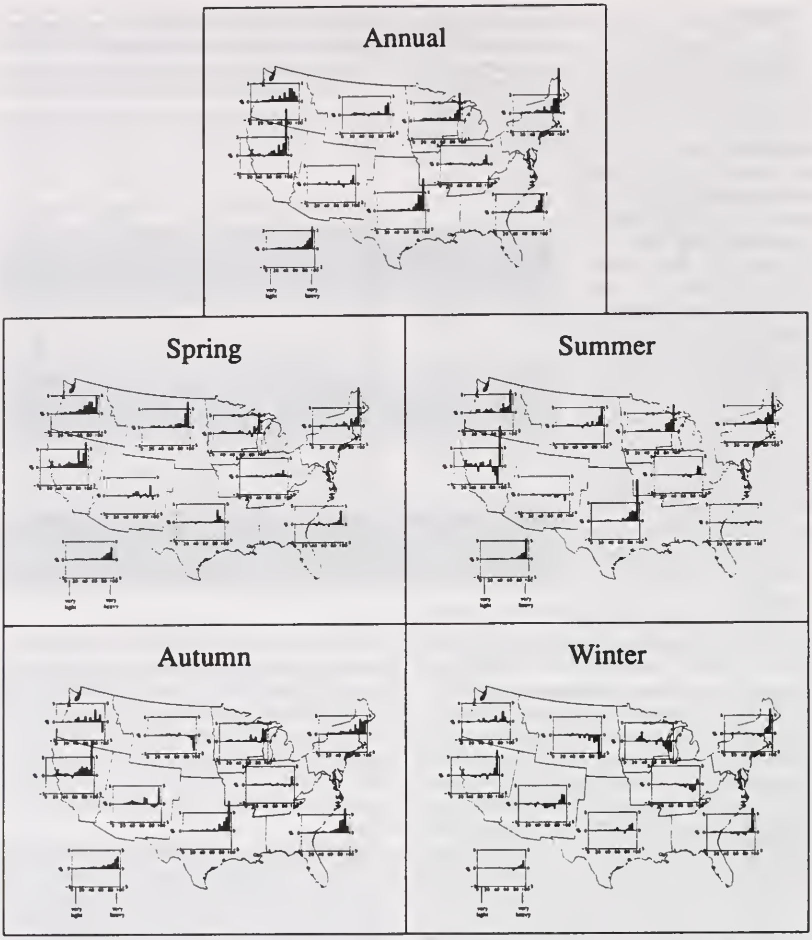

Fig. 1. Trends (1910–96) expressed as percent of mean precipitation per century for various categories of precipitation defined by five percentile class intervals. Value plotted at the 95th percentile represents the trend for the 95th to the highest percentiles, value plotted for the 90th percentile represents the trend for the 90th to the 95th percentile. Value plotted at 5th percentile represents the trend from the lowest percentile to the 5th percentile. The bar chart in the lower left reflects the national average.

cally significant increase in the number of precipitation events. There is a slight tendency, however, for this to be most pronounced for the light precipitation categories. On a seasonal basis, the summer and winter (Fig. 3) have the smallest increases in frequency, with winter having just a slight increase in precipita-

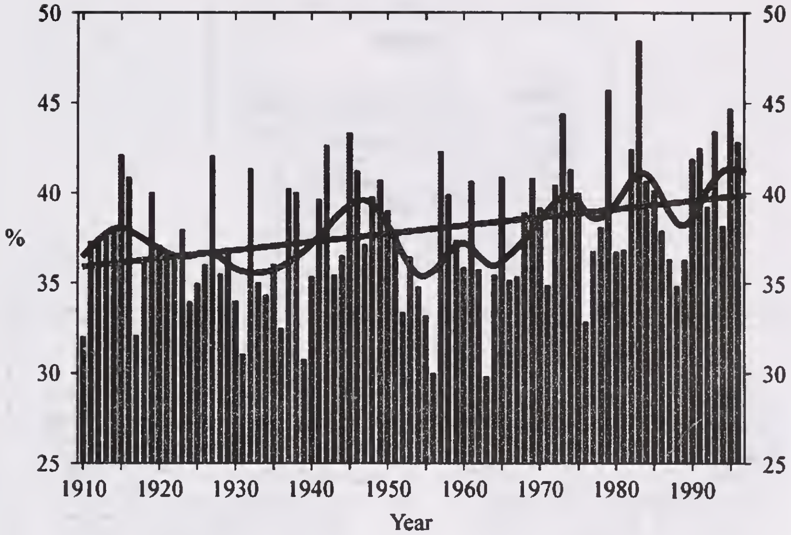

FIG. 2. Time series of the percent contribution of the upper 10 percentile of daily precipitation events to the total annual precipitation area-averaged across the United States. Smooth curve is a nine-point binomial filter, and the trend is also depicted.

tion frequency (< 0.5 days per century) followed by summer (1.3 days per century). Increases in the days with precipitation were significantly higher for the spring and autumn with 2.2 and 2.3 more precipitation days per century, respectively. These latter increases are fairly evenly spread throughout the precipitation distribution (Fig. 3). Clearly, the total annual increase in precipitation frequency of 6.3 days per century significantly contributes to the increase in precipitation.

Over the entire precipitation distribution, on a national basis, the increase in the number of days with precipitation contributed an amount equal to 87% of the total increase of precipitation. The contribution is strongest for the heavy and extreme precipitation categories (> 90th percentile) as depicted in Fig. 4. These two categories contributed about one-third of the total increase of precipitation given in Table 1 (10.1% per century). During the spring, summer, and autumn (Fig. 4), many of the large increases in frequency within each of the class intervals are statistically significant.

On an annual basis, trends of precipitation intensity (Fig. 5) reflect increases for the heavy and extreme precipitation categories, but only slight decreases throughout the rest of the distribution. This is apparent in most seasons (Fig. 5), but is particularly noteworthy for the highest precipitation class interval during summer. Here, like the annual increase, the increase in precipitation intensity is statistically significant at the $\alpha = 0.10$ significance level. For the upper 10 percentiles in the precipitation distribution, representing heavy and extreme precipitation amounts, the contributions to the total precipitation increase related to increased intensity versus frequency are about equal, 47% versus 53%, respectively. This is in contrast to the overall 13% contribution from intensity versus an 87% contribution from frequency to the total precipitation increase.

The trends in the extreme highest precipitation amount for each year-month also reflect the increase in intensity at the highest quantiles (Fig. 6). All areas reflect an increase in precipitation intensity for the highest quantile. Also depicted in Fig. 6 is the tendency for a decrease in precipitation intensity for the more

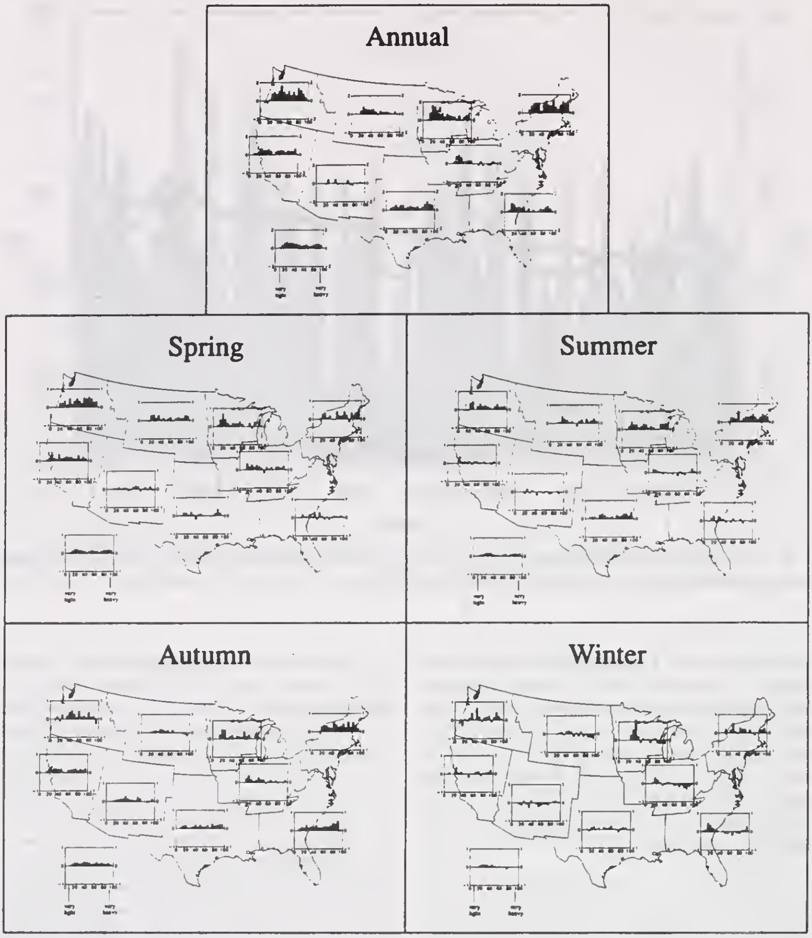

Fig. 3. The trend of the number of precipitation events expressed as events per century for the same percentiles as in Fig. 1.

moderate precipitation amounts, for example, the 50th percentile from each year-month as suggested in Fig. 5.

Given the increase in precipitation intensity at high precipitation amounts and the decrease at lower amounts (Fig. 5), the results of Karl et al. (1995) are easier to understand. They found an increase in the proportion of the total annual precipitation contributed by precipitation exceeding 50.8 mm (2 in.) day^{-1} across the United States. This is in contrast to the proportion of total annual precipitation contributed by precipitation events in more moderate categories (Fig. 7) between 2.54 and 25.4 mm (0.1 to 1 in.). These changes reflect

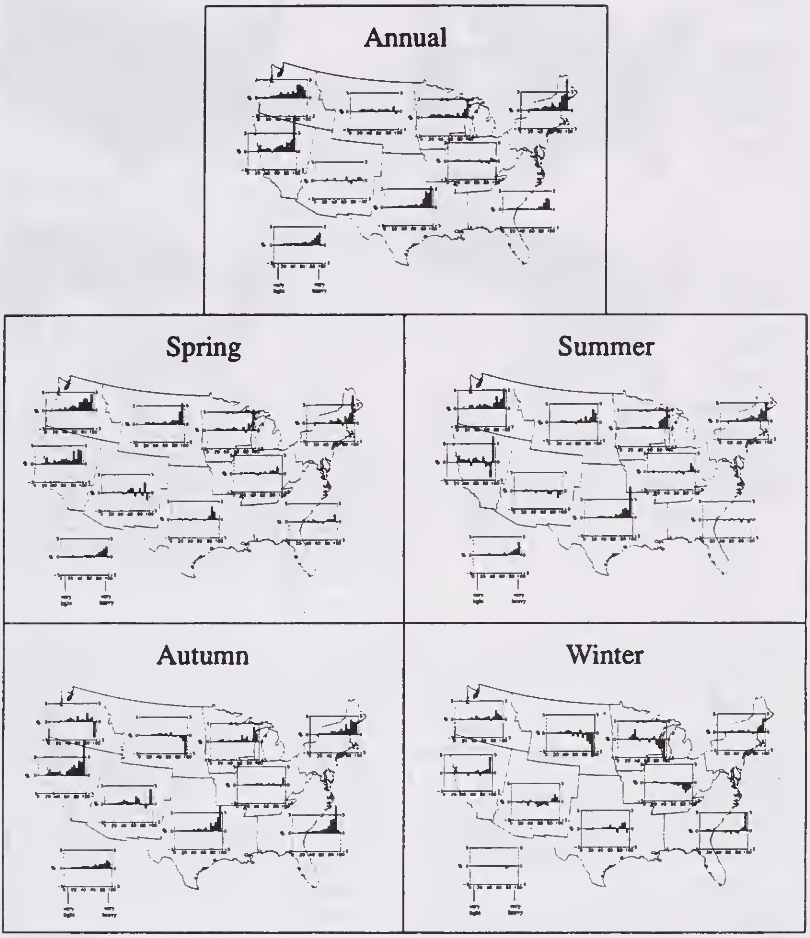

FIG. 4. The contribution to the trends in Fig. 1 attributed to trends in precipitation frequency. Trends are expressed as in Fig. 1.

a change in the precipitation distribution; for example, a change in the shape and/or scale parameters for a gamma distribution fit to daily precipitation amounts. The time series for the national average (Fig. 8) of the proportion of precipitation derived from events exceeding 50.8 mm day^{-1} reveals a statistically significant increase (2%) in area affected by a much above-normal frequency of these heavy and extreme events (Fig. 8).[3]

[3]Karl et al. (1996) published a similar time series, but the data presented here is based on an improved 1° × 1° grid-cell scheme. Trends are unchanged, but annual values differ from earlier work, sometimes substantially.

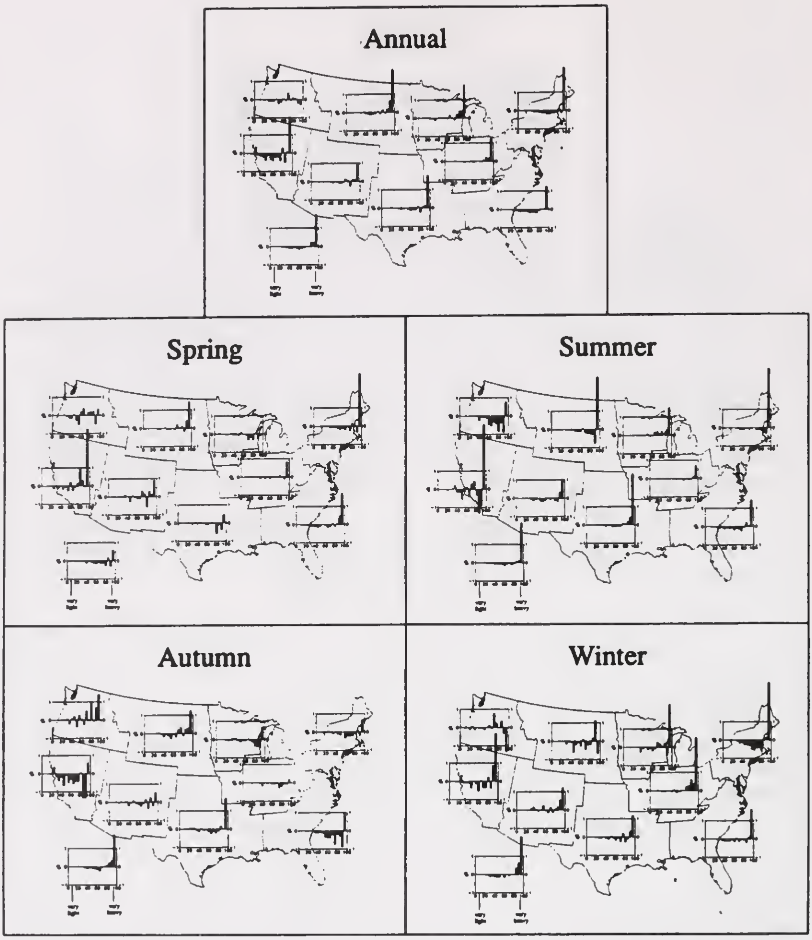

Fig. 5. The contribution to the trends in Fig. 1 attributed to trends in precipitation intensity. Trends are expressed as in Fig. 1.

5. Conclusions

Evaluating changes in precipitation extremes can be viewed using a variety of measures. In this analysis, simple methods to decompose the effect of changes in the frequency or probability of precipitation, and changes in precipitation intensity have been shown to uncover significant changes in U. S. precipitation extremes. Although it has been documented in several studies that precipitation is increasing in the United States, there are a variety of ways in which such an increase could have occurred. For example, precipita-

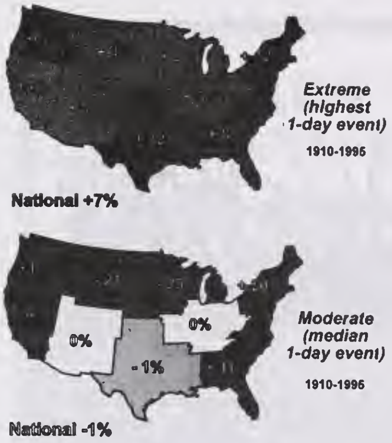

Fig. 6. Trends (1910–95) related to the highest daily year-month precipitation amount averaged throughout the year, and likewise for the medium precipitation amount. Trends are expressed as a percentage of the overall mean of the highest (median) daily year-month precipitation amount. Statistically significant trends are highlighted. The national trend is statistically significant at the $\alpha = 0.05$ level for the highest daily year-month values.

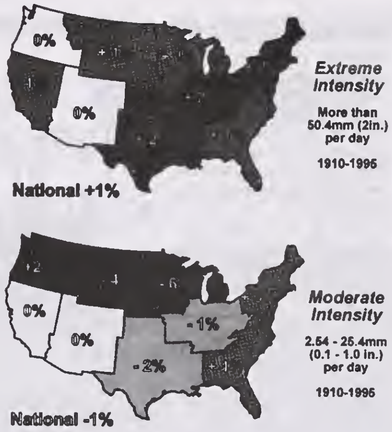

Fig. 7. Trends (1910–95) related to the proportion of total annual precipitation within various categories of precipitation. Trends are expressed as a percent change. Statistically significant trends are highlighted.

tion could have increased because a greater number of precipitation days in selective categories of precipitation, or it could have increased without any increase in precipitation frequency, but with an increase in precipitation intensity. What this analysis revealed is that in the United States over the past century, precipitation has increased in a fairly complex manner. For example,

- Increases of total precipitation are strongly affected by increases in both frequency and intensity of heavy and extreme precipitation events.
- The probability of precipitation on any given day has increased for all categories of daily precipitation amount.
- The intensity of precipitation has increased for very heavy and extreme precipitation days only.
- The proportion of total annual precipitation derived from heavy and extreme precipitation events has increased relative to more moderate precipitation.

As more daily data becomes available through data archeology efforts, similar analyses for other areas of the world will provide considerable information to better understand how the source term of the hydrologic cycle has varied and changed.

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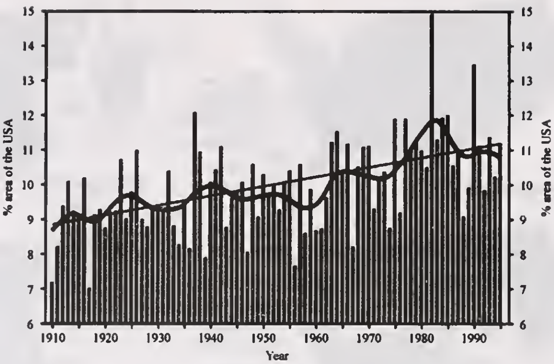

FIG. 8. Time series of the change in the area of the United States affected by a much above normal proportion of extreme precipitation events (daily precipitation exceeded 50.8

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Extreme Weather Events

Q9. On page 6 of your written testimony you state that "I want to emphasize that one can't point to any single extreme weather event today and say for sure that global warming caused it. But we can say that such events are examples of the kinds of impacts we expect to occur with greater frequency in a warmer world."

Please provide documentation of your statement that "such [extreme weather] events are examples of the kinds of impacts we expect to occur with greater frequency in a warmer world.

A9. Attached is a paper that was presented at the GCOS/CLIVAR climate extremes meeting in Asheville North Carolina last June. The paper is in press and will be published in *Climatic Change* and as part of a special collection of papers addressing climate extremes.

1

CONCEPTUAL FRAMEWORK FOR CHANGES OF EXTREMES OF THE HYDROLOGICAL CYCLE WITH CLIMATE CHANGE

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Abstract. A physically based conceptual framework is put forward that explains why an increase in heavy precipitation events should be a primary manifestation of the climate change that accompanies increases in greenhouse gases in the atmosphere. Increased concentrations of greenhouse gases in the atmosphere increase downwelling infrared radiation, and this global heating at the surface not only acts to increase temperatures but also increases evaporation which enhances the atmospheric moisture content. Consequently all weather systems, ranging from individual clouds and thunderstorms to extratropical cyclones, which feed on the available moisture through storm-scale moisture convergence, are likely to produce correspondingly enhanced precipitation rates. Increases in heavy rainfall at the expense of more moderate rainfall are the consequence along with increased runoff and risk of flooding. However, because of constraints in the surface energy budget, there are also implications for the frequency and/or efficiency of precipitation. It follows that increased attention should be given to trends in atmospheric moisture content, and datasets on hourly precipitation rates and frequency need to be developed and analyzed as well as total accumulation.

1. Introduction

The character of precipitation, with highly variable rain rates and enormous spatial variability, makes simply determining mean precipitation difficult let alone how it will change as the climate changes. For instance, a detailed examination of spatial structure of daily precipitation amounts by Osborne and Hulme (1997) shows that in Europe the average separation distance between climate stations where the correlation falls to 0.5 is about 150 km in summer and 200 km in winter — the more convective nature of summer precipitation is responsible for the difference. In addition, this complexity also makes it difficult to model precipitation reliably, as many of the processes of importance can not be resolved by the model grid (typically 200 km) and so sub-grid-scale processes have to be parameterized. Yet

[1] The National Center for Atmospheric Research is sponsored by the National Science Foundation.

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there are some overall aspects of precipitation related to the hydrological cycle that can be clarified and for which expectations as to how they will change are physically based. Here the processes involved that influence precipitation and link it to evaporation and heating are outlined along with the importance of dealing not just with accumulated amounts, but also precipitation rates (or intensity) and precipitation frequency. The relative roles of moisture stored in the atmosphere, its advection, and resupply have been examined in detail in Trenberth (1998), and only a brief summary of those aspects are included here.

The term "global warming" is often taken to refer to global increases in temperature accompanying the increases in greenhouse gases in the atmosphere. In fact it should refer to the additional global heating (sometimes referred to as radiative forcing, e.g., by the IPCC (1996)) arising from the increased concentrations of greenhouse gases, such as carbon dioxide, in the atmosphere. Increases in greenhouse gases in the atmosphere produce global warming through an increase in downwelling infrared radiation, and thus not only increase surface temperatures but also enhance the hydrological cycle, as much of the heating at the surface goes into evaporating surface moisture. This occurs in all climate models regardless of feedbacks, although the magnitude varies substantially (see section 3).

Temperature increases signify that the water-holding capacity of the atmosphere increases and, together with enhanced evaporation, the actual atmospheric moisture should increase, as is observed to be happening in many places (Hense et al. 1988, Gaffen et al. 1991, Ross and Elliott 1996, Zhai and Eskridge 1997). Of course, enhanced evaporation depends upon the availability of sufficient surface moisture and over land, this depends on the existing climate. However, it follows that naturally-occurring droughts are likely to be exacerbated by enhanced potential evapotranspiration. Further, globally there must be an increase in precipitation to balance the enhanced evaporation but the processes by which precipitation is altered locally are not well understood.

It is shown that precipitating systems of all kinds feed mostly on the moisture already in the atmosphere at the time the system develops, and precipitation occurs through convergence of available moisture on the scale of the system. Hence, the atmospheric moisture content directly affects rainfall and snowfall rates, but not so clearly the precipitation frequency and thus total precipitation, at least locally. Thus, it is argued that global warming leads to increased moisture content of the atmosphere which in turn favors stronger rainfall events, as is observed to be happening in many parts of the world (Karl et al. 1995), thus increasing risk of flooding. It is further argued that one reason why increases in rainfall should be spotty is because of mismatches in the rates of rainfall versus evaporation. The arguments assembled here imply the need for new observations, datasets, and ways of analyzing both model and observed data. Trenberth (1998) discusses these aspects more fully.

2. Atmospheric moisture cycling

New estimates of the moistening of the atmosphere through evaporation at the surface and of the drying of the atmosphere through precipitation are given in Trenberth (1998). These are simple estimates based on the precipitable water and average local evaporation and precipitation rates, which ignore transport. Overall for the global annual mean, the e-folding residence time (the time for amounts to fall by a factor $e = 2.718$) for atmospheric moisture is just over 8 days. For precipitation, local values of e-folding residence time of the atmospheric depletion rate of moisture are less than a week in the tropical convergence zones but they exceed a month in the dry zones in the subtropics and desert areas. Time constants for depletion and restoration rates of atmospheric moisture are fairly similar overall, but this conclusion does not take account of the fact that rain falls only a small fraction of the time. In midlatitudes precipitation typically falls from zero to 30% of the time, and so rainfall rates, conditional on when rain is falling, are much larger than evaporation rates. The depletion rate time scale is about 4 hours in the tropics when rain is falling. In middle latitudes, typical unconditional rainfall rates are 3 mm/day, but with rain falling about 10% of the time and precipitable water amounts of 15 mm, the depletion rate time scale of 5 days drops conditionally on rain falling to about 12 hours (Trenberth 1998). This inferred imbalance in the drying versus moistening of the atmosphere implies that most of the moderate and heavy rain that falls comes directly from the precipitable water already in the atmosphere at the time the storm responsible for the precipitation developed, not directly from evaporation, and so the lifetime of moisture in the atmosphere and its availability to rain systems is a limiting factor. However, atmospheric depletion of moisture by light rain could easily be restored by evaporation.

These above aspects do not take moisture transport into account. Therefore new estimates have also been made of how much precipitated moisture comes from evaporation from within versus transport from outside a domain, called recycling. Approximate values of recycling are computed following the approach of Brubaker et al. (1993), as detailed in Trenberth (1998). Equilibrium conditions are assumed, so that there are no changes in atmospheric moisture content but changes in moisture storage in the atmosphere do not impact the results for seasonal or longer averages. A domain of length L aligned along the trajectory of the air is considered. An important assumption is that the atmosphere is well mixed so that the ratio

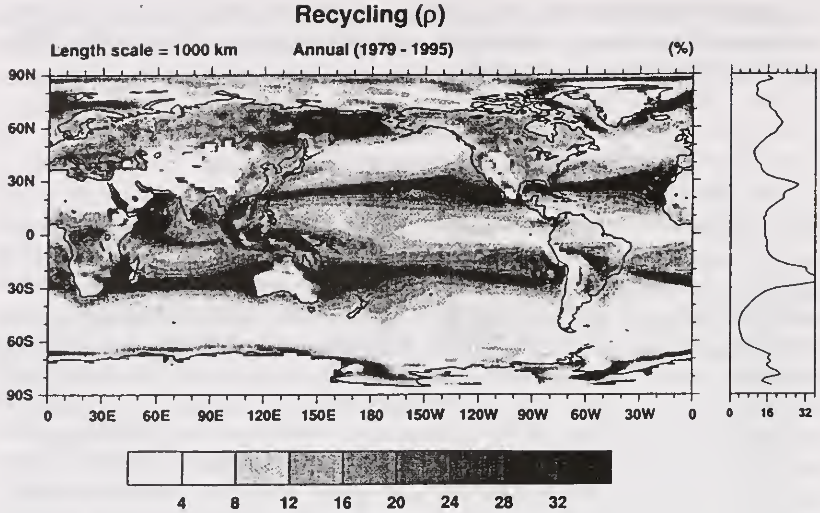

Figure 1. The recycling, for annual mean conditions, for length scales of 1,000 km, and using E and moisture flux from the NCEP reanalyses (Kalnay et al. 1996) and P from CMAP (Xie and Arkin 1997). Values are set to missing (white) where the surface pressure is less than 800 mb.

of precipitation that falls arising from advection versus local evaporation is equal to the ratio of average advected to evaporated moisture in the air. While interest has often been on recycling estimates for large drainage basins, the heterogeneity of the land surface is such that the recycling clearly varies substantially over the basins. The regions of mountains (where surface pressures are less than 800 mb) are screened out from the calculation, as those are regions where the moisture flux is small and there are huge variations over short distances owing to orographic effects on rainfall.

In Trenberth (1998) recycling results for annual means are presented for L= 500 km. Here results presented for L= 1000 km (Fig. 1) reveal recycling percentages of about 8 to 20% over land typically. For 500 km scales the global mean is 9.6%, consisting of 8.9% over land and 9.9% over the oceans and for 1000 km scales the mean recycling is 16.8% globally, 15.4% over land and 17.3% over the oceans. Over the Amazon, the average is about 10% and over the Mississippi basin about 12%. These values prove to be compatible with most previous extimates (e.g., Brubaker et al. 1993) once the different scales of the basins are taken into account. It is worth pointing out that the larger values previously obtained for the Amazon versus the Mississippi are mostly a result of the scale of the domain.

The recycling fraction depends greatly on the magnitude of the total moisture flux. In the computations, this includes advection by the mean flow as well as the transient eddies. Relatively high values (>30%) of recycling occur either in the subtropical highs, where evaporation E is high and the advective moisture flux is small, or in convergence zones where, again, the advective moisture flux is small. Low values occur over the southern oceans, the North Pacific, and the eastern equatorial Pacific, where the moisture flux is at a maximum. All of these recycling values show that on average less than 20% of the precipitation that falls comes from evaporation within a distance of about 1000 km. Therefore the results reinforce the arguments given above concerning the importance of transport of moisture and local storage in feeding precipitating systems.

The dominant storm-scale process in both thunderstorms and extratropical storms is the convergence of moisture by the storm-scale circulation. The latter determines how much moisture is available to the system and can vary in size from a few tens of kilometers to over 2000 km spatial scales. The advected moisture may combine with the in situ moisture to feed the storm but it is not all available as the relative humidity can not be reduced to zero, except perhaps approximately in strong down drafts very locally. The efficiency of thunderstorms is observed to vary from about 20% to 50%. "Precipitation efficiency" is defined as the ratio of the water mass precipitated to the mass of water vapor entering the storm through its base (e.g., Fankhauser 1988) or the ratio of total rainfall to total condensation in modeling studies (e.g., Ferrier et al. 1996).

In the United States, much of the moisture for precipitation, especially in the winter half year, comes from moisture transported out of the subtropics often in a southwesterly flow ahead of cold fronts. For storms east of the Rockies, moisture flows northwards from the Gulf of Mexico or subtropical Atlantic. At advection rates of 12 m s^{-1} (which is the standard deviation of the northward velocity component at 850 mb just north of the Gulf of Mexico in January), the moisture travels over 1,000 km in a day, so that moisture from the Gulf can be readily precipitated out over the Great Plains or Ohio Valley just a day or so later. In major storms, transient northward advection rates often exceed 20 m s^{-1} at 850 mb. In the western United States, the moisture comes from the subtropical Pacific. Therefore much of the extratropical precipitation originates from moisture advected from the Gulf of Mexico and subtropical Atlantic or Pacific a day or so earlier and it is estimated that about 70% to 75% of the moisture in an extratropical storm comes from moisture that was stored in the atmosphere at the beginning of the storm and brought into the region by the storm-scale circulation. For thunderstorms, whose life is a few hours, nearly all of the precipitated moisture comes from moisture that was already in the atmosphere at the time the storm began.

3. Relevance to climate change

The above discussion reveals the mismatch between precipitation rates and evaporation, so that moderate and heavy precipitation, which contributes most to the total accumulation, depends upon the moisture already in the atmosphere and the advection and resupply of moisture by the storm circulation. These points are pertinent to climate change experiments with global climate models. However, most climate model studies have not analyzed the results in a way that throws light on these aspects. The surface heat budget is especially relevant.

There are many feedback processes in nature that can either amplify or diminish the climate response to increases in greenhouse gases. The net radiative forcing or "warming" at the surface depends critically on these and the surface heat budget. In every case it seems that at the surface there is an increase in downwelling infrared radiation associated with both the greenhouse effect from carbon dioxide and other greenhouse gases, as well as changes in water vapor and clouds. In some models, changes in clouds produce an offset by reducing shortwave radiation, but the net energy available from radiation at the surface is increased in spite of the greater surface emissions associated with the higher temperatures. Moreover, changes in the sensible heat flux also act to warm the surface because of stabilization of the lower atmosphere (Boer 1993, Roads et al. 1996).

This leaves only the latent heat flux through increased evaporation to compensate and balance the surface heat budget. The latent heat flux, which ranges from 3 to 10 W m^{-2} for CO_2 doubling for the four models considered by Boer (1993), determines the global enhancement of the hydrological cycle and average precipitation rate (of about 3 to 10%). However, the atmospheric moisture content increases by about 20% (Mitchell et al. 1987) or more (in the case of the CCM2, Roads et al. 1996) although with very little change in model relative humidity. With other things kept constant, moisture convergence would be enhanced by the same amount and should lead to similarly enhanced precipitation. But a 20% increase in precipitation cannot occur because of the limitations associated with the surface energy budget. Nevertheless such mechanisms should take place for individual storms, whether thunderstorms, or extratropical cyclones, leading to increased rainfall rates. If this is the case, however, there are implications for the frequency of storms or other factors that must come into play to restrict the total precipitation.

One factor clearly of importance is that the moisture increases are not uniform. Generally, evaporative cooling is more important in the tropics and subtropics. Bigger increases occur in lower latitudes because of the non-linear nature of the Clausius-Clapeyron equation in spite of larger increases in surface temperatures at high latitudes. Thus much of this moisture may not be within reach of many extratropical storms. Another factor is the precipitation efficiency, discussed above. How precipitation efficiency might change with climate change is not known and this is not a factor that can be dealt with by current climate models. Warmer conditions could imply that more moisture might remain in the atmosphere if this is determined by relative humidity, as is likely. Therefore the rainfall may not increase in direct proportion to the moisture convergence, because more moisture is left in the atmosphere.

In most models, surface temperature increases with increased greenhouse gases are greatest in the Arctic, in part because of ice-albedo feedback, so that the meridional surface temperature gradient and baroclinicity is reduced, although this may not be the case above the surface. Therefore another factor relates to extratropical storms and the overall baroclinicity, as argued by Held (1993). Held notes that one effect of increased moisture content in the atmosphere is to enhance the latent heating in such storms and thereby increase their intensity. But he also notes that more moist air would be transported polewards, reducing the required poleward energy transports normally accomplished by baroclinically unstable eddies and the associated poleward down-gradient heat transports. He therefore argues that this would contribute to "smaller eddies" and a decrease in eddy amplitudes. While recognizing that both effects are important, Held suspects that the latter is dominant. There are other possibilities not considered by Held. In particular, individual storms could be more intense from the latent heat enhancement, but fewer and farther between. Changes in the vertical temperature structure (the lapse rate) will also play a role in such storms.

Therefore the other major factor worth considering in more detail is the frequency of precipitation events. The above discussion suggests that for rain rates to increase faster than rain amounts, then the frequency of rain should decrease. However, this would only apply globally. A preliminary examination of trends in frequency of precipitation events for the United States computed over the period 1963 to 1994 in Trenberth (1998) shows that the most notable statistically significant trends are for increases in the southern United States in winter and decreases in the Pacific Northwest from November through January, which may be related to changes in atmospheric circulation and storm tracks associated with the trend toward more El Niño events (Trenberth and Hoar 1996). For instance, an example has been the 1997-98 El Niño winter which featured heavy rains across the southern states from California to Florida, while somewhat drier conditions generally prevailed across the northern states.

These aspects have been explored only to a limited extent in climate models. None deal with true intensity of rainfall, which requires hourly (or higher resolution) data, as the analysis is of daily rainfall amounts. Cubasch et al. (1995) and Hennessy et al. (1997) have analyzed changes in intensity and frequency in coarse resolution models with increased CO_2. Cubasch et al. note that while precipitation change does not display a clear signal, increases in rain intensity and dry periods are simulated in the ECHAM3 model. The UKHI and CSIRO9 models (Hennessy et al. 1997) are consistent in showing heavier rainfall events with doubled CO_2, a general decrease in the probability of moderate precipitation, and an increase in no or light precipitation. Return periods for extreme events whose period is greater than one year decrease by factors of 2 to 5. Hennessy et al. further argue that the frequency of precipitation should be expected to decrease with increases in intensity, and find this to be true in the model simulations for the most part.

An analysis by Mearns et al. (1995) used a nested regional model with 60 km resolution for regions of the United States for control and doubled-carbon dioxide results. They explored the frequency and intensity of modeled precipitation but only for daily values, not the true precipitation rates. Results revealed increased daily rainfall variability under doubled CO_2. There are some areas where frequency of precipitation decreases but precipitation mean daily amounts increase. Overall, however, they find both increases and decreases of both precipitation frequency and intensity. Jones et al. (1997) produced results over Europe using a similar technique and a nested model with 50 km resolution. They find a substantial increase in precipitation intensity in extreme events, and were able to trace most of that increase simply to the increased atmospheric moisture concentrations in the models. While moderate precipitation decreased, the frequency of dry days also increased along with an increase in evaporation, and so these were all symptoms of an increased hydrological cycle.

4. Conclusions and recommendations

The arguments on how climate change can influence moisture content of the atmosphere, and its sources and sinks are assembled in the schematic in Fig. 2. This provides the sequence described earlier. The sequence given is simplified by omitting some of the feedbacks that can interfere. For example, an increase in atmospheric moisture may lead to increased relative humidity and increased clouds, which could cut down on solar radiation (enhance shortwave cloud forcing) and reduce the energy available at the surface for evaporation. Those feedbacks are included in the climate models and alter the magnitude of the surface heat available for evaporation in different models but not its sign. Figure 2 provides the rationale for why rainfall rates and frequencies as well as accumulations are important in understanding

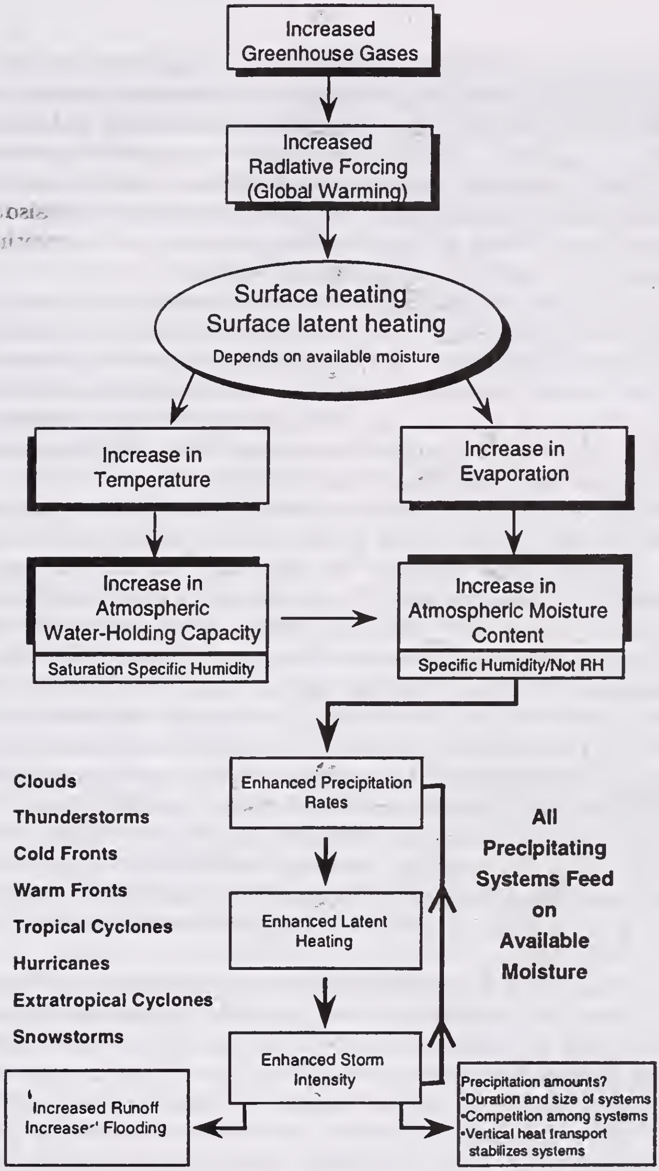

Figure 2. Schematic outline of the sequence of processes involved in climate change and how they alter moisture content of the atmosphere, evaporation, and precipitation rates. All precipitating systems feed on the available moisture leading to increases in precipitation rates and feedbacks.

what is going on with precipitation locally. The accumulations depend greatly on the frequency, size and duration of individual storms, as well as the rate (Byers 1948) and these depend on static stability and other factors as well. In particular, the need to vertically transport heat absorbed at the surface is a factor in convection and baroclinic instability both of which act to stabilize the atmosphere. Increased greenhouse gases also stabilize the atmosphere. Those are additional considerations in interpreting model responses to increased greenhouse gas simulations.

Another clearly important factor in interpreting observed and modeled changes, not explored here, is the changes in atmospheric circulation which can alter the location and intensity of storm tracks and thereby lead to dipole structures in precipitation changes, with decreases in rainfall in some areas and increases in others. For example, Trenberth and Guillemot (1996) show how storm tracks changed across North America to help bring about the spring-summer 1988 drought and 1993 floods.

There is firm evidence that moisture in the atmosphere is increasing. In the Western Hemisphere north of the equator, annual mean precipitable water amounts below 500 mb are increasing over the United States, Caribbean and Hawaii by about 5% per decade as a statistically significant trend from 1973 to 1993 (Ross and Elliott 1996), and these correspond to significant increases in relative humidities of 2 to 3% per decade over the Southeast, Caribbean and subtropical Pacific. Precipitable water and relative humidities are not increasing significantly over much of Canada, however, and are decreasing slightly in some areas. In China, recent analysis by Zhai and Eskridge (1997) also reveals upward trends in precipitable water in all seasons and for the annual mean from 1970 to 1990. Earlier, Hense et al. (1988) revealed increases in moisture in the western Pacific. A claim for recent drying in the tropics by Schroeder and McGuirk (1998) using TOVS data is questionable owing to the changes in instruments and satellites. Clearly, there is a need to obtain more reliable atmospheric moisture trends over the entire globe.

Moreover, there is clear evidence that rainfall rates have changed in the United States. The incidence of heavy rainfall events has steadily increased at the expense of moderate rainfall events throughout this century. This has been shown by an analysis of the percentage of the U.S. area with much above normal proportion of total annual precipitation from 1 day extreme events, where the latter are defined to be more than 2 inches (50.8 mm) amounts (Karl et al. 1996). The "much above normal proportion" is defined to be the upper 10%. This quantity can be reliably calculated from 1910, and the percentage has increased steadily from less than 9 to over 11%, a 20% change. Karl and Knight (1998) have provided further analysis of U.S. precipitation increases and show how it occurs mostly in the upper tenth percentile of the distribution and that the portion of total precipitation derived from extreme and heavy events is increasing at the expense of more moderate events. Other evidence for increasing precipitation rates occurs in Japan (Iwashima and Yamamoto 1993) and Australia (Suppiah and Hennessy 1996).

It has been argued that increased moisture content of the atmosphere favors stronger rainfall and snowfall events, thus increasing risk of flooding. As noted, there is a pattern of heavier rainfalls observed in many parts of the world where the analysis has been done. However, flooding records are confounded by changes in land use and increasing settlement of flood plains. Moreover, because there is a disparity between the rates of increase of atmospheric moisture and precipitation, there are implied changes in the frequency of precipitation and/or efficiency of precipitation (related to how much moisture is left behind in a storm).

These arguments may help to explain the exceptional rain and snow falls over the U.S. in the winter of 1996-97. These included heavy rains and flooding in the Pacific Northwest in early January, where observed increases in moisture content of the atmosphere at Hawaii and in the subtropical Pacific (Ross and Elliott 1996) are especially pertinent. Also, heavy snowfalls in the Great Plains and Upper Mississippi Basin led to extensive flooding in the spring of 1997 as snows melted, and heavy rains in the Ohio River Valley which, along with snow melt, also produced extensive flooding. Note that the primary argument here is not that these flooding events would not have occurred but that they have probably been enhanced, perhaps by as much as 10%, because of the increased moisture in the atmosphere, over what would have occurred two decades ago.

The above arguments suggest that there is not such a clear expectation on how local total precipitation amounts should change, except as an overall global average. With higher average temperatures in winter expected, more precipitation is likely to fall in the form of rain rather than snow, which will increase both soil moisture and run off, as noted by the IPCC (1996) and found in many models. In addition, faster snow melt in spring is likely to aggravate springtime flooding. In other places, dipole-like structures of precipitation change should occur in places where storm tracks shift meridionally. Beyond this, it is suggested that examining moisture content, rainfall rates and frequency of precipitation and how they change with climate change may be more important and fruitful than just examining precipitation amounts in understanding what is happening in model projections. To be compatible with life times of significant rain events, yet still deal with whole storms rather than individual rain cells, hourly precipitation data are recommended. Such data are also retrievable from climate models.

Acknowledgments

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KEYWORDS:
Hydrological cycle
climate change
precipitation
atmospheric moisture

IPCC "Business As Usual" Scenario

Q10. On page 6 of your written testimony you discuss the IPCC "business as usual" scenario.

Please provide a listing of all IPCC "business as usual" scenario assumptions.

A10. Table 1 on p. 3 of the IPCC report *Climate Change 1995 – Impacts, Adaptations and Mitigation of Climate Change: Scientific – Technical Analyses* is headed "Summary of assumptions in the six IPCC 1992 alternative scenarios." The source of the information in this table is given as the IPCC report, *Climate Change 1992 – the Supplemental Report to the IPCC Scientific Assessment*. A copy of the table and of Chapter A3 ("Emissions Scenarios for IPCC: An Update") from the 1992 report are attached. All of the IPCC scenarios represent plausible "business-as-usual" scenarios. They differ in assumptions made about population size, economic growth rates, and energy technology "mix." In practice, IS92a is most often used to represent the "business as usual" case because it is the most central scenario.

1. Scope of the Assessment

The charge to Working Group II of the Intergovernmental Panel on Climate Change (IPCC) was to review the state of knowledge concerning the impacts of climate change on physical and ecological systems, human health, and socioeconomic sectors. Working Group II also was charged with reviewing available information on the technical and economic feasibility of a range of potential adaptation and mitigation strategies. This assessment provides scientific, technical, and economic information that can be used, *inter alia*, in evaluating whether the projected range of plausible impacts constitutes "dangerous anthropogenic interference with the climate system," as referred to in Article 2 of the United Nations Framework Convention on Climate Change (UNFCCC), and in evaluating adaptation and mitigation options that could be used in progressing towards the ultimate objective of the UNFCCC (see Box 1).

Box 1. Ultimate Objective of the UNFCCC (Article 2)

"...stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened, and to enable economic development to proceed in a sustainable manner."

2. Nature of the Issue

Human activities are increasing the atmospheric concentrations of greenhouse gases—which tend to warm the atmosphere—and, in some regions, aerosols—which tend to cool the atmosphere. These changes in greenhouse gases and aerosols, taken together, are projected to lead to regional and global changes in climate and climate-related parameters such as temperature, precipitation, soil moisture, and sea level. Based on the range of sensitivities of climate to increases in greenhouse gas concentrations reported by IPCC Working Group I and plausible ranges of emissions (IPCC IS92; see Table 1), climate models, taking into account greenhouse gases and aerosols, project an increase in global mean surface temperature of about 1–3.5°C by 2100, and an associated increase in sea level of about 15–95 cm. The reliability of regional-scale predictions is still low, and the degree to which climate variability may change is uncertain. However, potentially serious changes have been identified, including an increase in some regions in the incidence of extreme high-temperature events, floods, and droughts, with resultant consequences for fires, pest outbreaks, and ecosystem composition, structure, and functioning, including primary productivity.

Table 1: Summary of assumptions in the six IPCC 1992 alternative scenarios.

Scenario	Population	Economic Growth	Energy Supplies
IS92a,b	World Bank 1991 11.3 billion by 2100	1990–2025: 2.9% 1990–2100: 2.3%	12,000 EJ conventional oil 13,000 EJ natural gas Solar costs fall to $0.075/kWh 191 EJ of biofuels available at $70/barrel[a]
IS92c	UN Medium-Low Case 6.4 billion by 2100	1990–2025: 2.0% 1990–2100: 1.2%	8,000 EJ conventional oil 7,300 EJ natural gas Nuclear costs decline by 0.4% annually
IS92d	UN Medium-Low Case 6.4 billion by 2100	1990–2025: 2.7% 1990–2100: 2.0%	Oil and gas same as IS92c Solar costs fall to $0.065/kWh 272 EJ of biofuels available at $50/barrel
IS92e	World Bank 1991 11.3 billion by 2100	1990–2025: 3.5% 1990–2100: 3.0%	18,400 EJ conventional oil Gas same as IS92a,b Phase out nuclear by 2075
IS92f	UN Medium-High Case 17.6 billion by 2100	1990–2025: 2.9% 1990–2100: 2.3%	Oil and gas same as IS92e Solar costs fall to $0.083/kWh Nuclear costs increase to $0.09/kWh

[a]Approximate conversion factor: 1 barrel = 6 GJ.
Source: IPCC, 1992: Emissions scenarios for IPCC: an update. In: *Climate Change 1992: The Supplementary Report to the IPCC Scientific Assessment* [J.T. Houghton, B.A. Callander, and S.K. Varney (eds.)]. Section A3, prepared by J. Leggett, W.J. Pepper, and R.J. Swart, and WMO/UNEP. Cambridge University Press, Cambridge, UK, 200 pp.

Climate Change 1995

Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses

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Emissions Scenarios for the IPCC: an Update

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EXECUTIVE SUMMARY

Scenarios of net greenhouse gas and aerosol precursor emissions for the next 100 years or more are necessary to support study of potential anthropogenic impacts on the climate system. The scenarios both provide inputs to climate models and also assist in assessing the relative importance of relevant trace gases and aerosol precursors in changing atmospheric composition and hence climate. Scenarios can also help to improve the understanding of key relationships among factors that drive future emissions.

Scenarios are not predictions of the future and should not be used as such. This becomes increasingly true as the time horizon increases, because the basis for the underlying assumptions becomes increasingly speculative. Considerable uncertainties surround the evolution of the types and levels of human activities (including economic growth and structure), technological advances, and human responses to possible environmental, economic and institutional constraints.

Since completion of the 1990 Scenario A (SA90), events and new information have emerged which relate to that scenario's underlying assumptions. These developments include: the London Amendments to the Montreal Protocol; revision of population forecasts by the World Bank and the United Nations; publication of the IPCC Energy and Industry Sub-group scenario of greenhouse gas emissions to AD 2025; political events and economic changes in the former USSR, Eastern Europe and the Middle East; re-estimation of sources and sinks of greenhouse gases (reviewed in this Assessment); revision of preliminary FAO data on tropical deforestation; and new scientific studies on forest biomass.

These factors have led to an update of SA90, the current exercise providing an interim view and laying a basis for a more complete study of future emissions. Six alternative IPCC scenarios (IS92a-f) now embody a wide array of assumptions affecting how future greenhouse gas emissions might evolve in the absence of climate policies beyond those already adopted. The different worlds which the new scenarios imply, in terms of economic, social and environmental conditions, vary widely and the resulting range of possible greenhouse gas futures spans almost an order of magnitude. Overall, the scenarios indicate that greenhouse gas emissions could rise substantially over the coming century in the absence of new and explicit control measures. IS92a is closer to SA90 due to modest and largely offsetting changes in the underlying assumptions. The highest greenhouse gas levels result from IS92e which combines, among other assumptions, moderate population growth, high economic growth, high fossil fuel availability and eventual hypothetical phase-out of nuclear power. At the other extreme, IS92c has a CO_2 emission path which eventually falls below its 1990 starting level. It assumes that population grows, then declines by the middle of the next century, that economic growth is low, and that there are severe constraints on fossil fuel supplies. IS92b, a modification of IS92a, suggests that current commitments by many OECD Member countries to stabilize or reduce CO_2 might have a small impact on greenhouse gas emissions over the next few decades, but would not offset the substantial growth in the rest of the world. IS92b does not take into account the possibility that such commitments could accelerate development and diffusion of low greenhouse gas technologies, nor possible resulting shifts in industrial mix.

Population and economic growth, structural changes in economies, energy prices, technological advance, fossil fuel supplies, nuclear and renewable energy availability are among the factors which could exert a major influence on future levels of CO_2 emissions. Developments such as those in the republics of the former Soviet Union and in Eastern Europe, now incorporated into all the scenarios, have important implications for future fossil fuel carbon emissions, by affecting the levels of economic activities and the efficiency of energy production and use. Biotic carbon emissions in the early decades of the scenarios are higher than SA90, reflecting higher preliminary FAO estimates of current rates of tropical deforestation in many - though not all - parts of the world, and higher estimates of forest biomass.

The revised scenarios for CFCs and other substances which deplete stratospheric ozone are much lower than in SA90. This is consistent with wide participation in controls under the 1990 London Amendments to the Montreal Protocol. However, the future production and composition of CFC substitutes (HCFCs and HFCs) could significantly affect the levels of radiative forcing from these compounds.

The distribution of CH_4 and N_2O emissions from their respective sources has changed from the SA90 case. CH_4 emissions from rice paddies are lower, and emissions from animal waste and biomass burning have also been revised downwards. Adipic and nitric acid production have been included as additional sources of N_2O. Preliminary analysis of the emissions of volatile organic compounds and sulphur dioxide suggests that the global emissions of these substances are likely to grow substantially in the coming century.

A3.1 Introduction and Background

In January 1989, the Response Strategies Working Group (RSWG) of the Intergovernmental Panel on Climate Change (IPCC) requested a United States/Netherlands expert group to prepare a set of scenarios of global emissions of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), halocarbons and the tropospheric ozone precursors nitrogen oxide (NO_x) and carbon monoxide (CO) (IPCC, 1991a). These scenarios were completed in December 1989 for use by the IPCC Science Working Group (WGI) in its assessment of future climate change (IPCC, 1990a and b). New information has become available since the development of the original scenarios. Consequently, in March 1991, the IPCC requested an update of the existing scenarios in light of recent developments and newly adopted policies. The new IPCC mandate explicitly excluded development of new climate policy scenarios (Swart *et al.*, 1991).

This Section first briefly compares the major assumptions on population and economic growth with historical data or other published forecasts. It then summarizes how the original no-climate-policy Scenario A (SA90) has been updated with information which has become available in 1990 and 1991. This produces the new IPCC Scenarios "IS92a" and "IS92b". Because of substantial uncertainty in how the future will evolve, this Section also includes a preliminary assessment of a range of additional no-climate-policy scenarios, as well as comparisons with other published greenhouse gas scenarios. The updated scenarios are set against two studies of the probability distributions of possible CO_2 scenarios, and then are compared to other published "central tendency" scenarios that extend past the year 2000 and up to the year 2100. Finally, we present sector-by-sector discussions of the particular methods and assumptions in the update, along with additional sectoral scenarios. Detailed documentation of the scenarios is available in a supporting document which also provides tabulations of key variables including population, GNP, primary energy consumption, and emissions (Pepper *et al.*, 1992).

A3.2 New Aspects of this Update

The following changes have occurred since the original IPCC scenarios were developed:

- revised World Bank and United Nations (UN) population forecasts;
- a new greenhouse gas scenario from the IPCC Energy and Industry Sub-Group (EIS);
- important political reforms in the USSR, Eastern Europe and other countries, and a war in the Persian Gulf;
- more optimistic assessments of the economical availability of renewable energy resources;
- revised estimates of current sources and sinks of greenhouse gases, reported in Section A1 of this report;
- revised Food and Agriculture Organization (FAO) data on rates of tropical deforestation and several new studies on forest biomass content; and
- the London Amendments to the Montreal Protocol as well as developments in participation and compliance with the Protocol entered into force.

For completeness, several small sources of greenhouse gases are added to this assessment which were not included in the 1990 IPCC Assessment Report. These include N_2O from the production of nitric acid and adipic acid, and CH_4 from animal wastes and domestic sewage (see Sections A1.3 and A1.4). In addition, scientific evidence described in Section A2 underscores the need to consider the full range of gases which influence climate, directly or indirectly. Cognizant of the importance of a comprehensive approach, this Section also provides preliminary estimates of present and future emissions of volatile organic compounds (VOC) and sulphur oxides (SO_x). Their indirect influences on radiative forcing are more uncertain than those of the direct greenhouse gases and it is not yet possible to quantify on an equivalent basis all the direct and indirect forcing. Improved information with which both to estimate the emissions of these gases and to summarize their effects is needed for future assessments.

The reader should be cautioned, however, that none of the scenarios depicted in this section predicts the future. Long-term scenarios provide inputs to climate models and assist in the examination of the relative importance of relevant trace gases, aerosols, and precursors in changing atmospheric composition and climate. Scenarios can also help improve understanding of key relationships among factors that drive future emissions. Scenarios illustrate the emissions which could be associated with an array of possible assumptions regarding demographics, economics, and technological advance. They can help policymakers to consider the directions in which future emissions may evolve in the absence of new greenhouse gas reduction efforts, and the types of change in important parameters which could or would have to occur in order to significantly change future emission paths.

The results of scenarios can vary considerably from actual outcomes even over short time horizons. Confidence in scenario outputs decreases as the time horizon increases, because the basis for the underlying assumptions becomes increasingly speculative. Uncertainties are of two types:

(i) large uncertainty associated with the evolution of future patterns of human activity, such as economic growth and structure, technological advances, or responses to environmental, economic, or institutional constraints: and

(ii) inadequacy of scientific knowledge concerning physical parameters, such as emission factors, and their relationships.

We have addressed some of these uncertainties in the updated IS92a and b in four ways. The first is through the creation of new scenarios (c through f explained in Table A3.1) using modified key parameters; the second compares some of the new IPCC scenarios with two studies which have mapped probability distributions of future CO_2 emissions; the third compares the range of new IPCC scenarios with other published studies of "central tendencies"; and the fourth analyses sensitivity of results in different sectors to key parameters. The current exercise lays a basis for more complete analysis of the credible range and probabilities of alternative scenarios.

A possibly important limitation of this analysis is that it does not assess the effects that climate change may have on agricultural production, energy demand, and terrestrial ecosystems. Nor does it make assumptions about growth of vegetation if CO_2 increases fertilization, or about losses of the forest uptake of CO_2 if deforestation continues. There could also be positive feedbacks on CO_2 and methane emissions through increased respiration of vegetation and degradation of organic soils. Also, as discussed in Section A2 of this report, we do not yet have an adequate method for summarizing on an equivalent basis the effects on climate of all the greenhouse gases.

A3.3 The Analytical Tool: The "Atmospheric Stabilization Framework"

The Atmospheric Stabilization Framework (ASF), developed by the US Environmental Protection Agency (EPA, 1990), was used as the primary tool for integrating the assumptions and estimating future emissions of greenhouse gases. The ASF is a framework which combines emission modules for various sectors including modules for energy, industry, agriculture, forests and land conversion, as well as a number of small sources. Each module combines assumptions concerning population, economic growth, structural change, resource availability, and emission coefficients to estimate emissions in future time periods. The ASF estimates emissions for CO_2, CH_4, N_2O, chlorofluorocarbons (CFCs) and substitutes, CO, NO_x, VOCs, and SO_x. The energy module uses energy prices to equilibriate supply from the different energy supply sources with demand in four energy end-use sectors. Increased energy prices encourage additional energy supply and increases in energy efficiency but have only a small feedback on economic growth. The agriculture module combines assumptions on population growth, economic growth, improved yields, and other factors to estimate future production and consumption of agricultural products, land use, and fertilizer use along with emissions of greenhouse gases from these activities. The CFC module estimates future emissions of CFCs, HCFCs, carbon tetrachloride (CCl_4), methyl chloroform, and HFCs under different policy objectives and compliance scenarios, derived with assumptions on the estimated growth in demand for CFCs. The tropical forest section combines assumptions including population, demand for agricultural land, method of forest clearing, and the amount of biomass stored in the vegetation and soils to estimate the clearing of tropical forests and the fate of the cleared land (e.g., forests may be cleared and then allowed to lie fallow in which case they can start to re-accumulate carbon).

A3.4 General Assumptions

The assumptions for the scenarios in this report come mostly from the published forecasts of major international organizations or from published expert analyses. Most of these have been subject to extensive review. The premises for the 1992 IPCC Scenarios a and b ("IS92a" and "IS92b") most closely update the SA90 scenario from IPCC (1990) There exist a wide variety of other plausible assumptions, some of which are used in the range of new scenarios presented here. Table A3.1 summarizes the different assumptions used in the six scenarios. These assumptions are documented in detail in a supporting report (Pepper *et al.*, 1992).

New information since the SA90 has raised the assumed population and economic growth rates compared to those in the earlier assessment. The forecast of future population growth in the SA90 came from the World Bank (Zachariah and Vu, 1988), which the World Bank has since revised (Bulatao *et al*, 1989). The UN has also published new population estimates (UN, 1990; UN Population Division, 1992). The UN medium case is very close to the World Bank's update; the UN medium-low and medium-high cases are used in the alternative scenarios presented here. Most of the variance between the medium-high and medium-low cases is in the developing countries. The updated World Bank population assumptions are close to 10% higher than the assumptions in the SA90: global population increases from 4.84 billion in 1985, to 8.42 billion in 2025, and to 11.33 billion in 2100, with about 94% of the growth occurring in the developing countries. The UN medium forecast of future population estimates that global population may reach 8.51 billion in 2025, 1% higher than the World Bank estimate. Their recent medium extension of this suggests world population of 11.18 billion in 2100 (UN Population Division, 1992), or about 1% lower than the World Bank's. The UN medium-low

Table A3.1: Summary of assumptions in the six IPCC 1992 alternative scenarios.

Scenario	Population	Economic Growth		Energy Supplies	Other	CFCs
IS92a	World Bank 1991 11.3 B by 2100	1990-2025: 1990-2100:	2.9% 2.3%	12,000 EJ Conventional Oil 13,000 EJ Natural Gas Solar costs fall to \$0.075/kWh 191 EJ of biofuels available at \$70/barrel †	Legally enacted and internationally agreed controls on SO_x, NO_x and NMVOC emissions. Efforts to reduce emissions of SO_x, NO_x and CO in developing countries by middle of next century.	Partial compliance with Montreal Protocol. Technological transfer results in gradual phase out of CFCs in non-signatory countries by 2075.
IS92b	World Bank 1991 11.3 B by 2100	1990-2025 1990-2100	2.9% 2.3%	Same as "a"	Same as "a" plus commitments by many OECD countries to stabilize or reduce CO_2 emissions.	Global compliance with scheduled phase out of Montreal Protocol.
IS92c	UN Medium-Low Case 6.4 B by 2100	1990-2025 1990-2100	2.0% 1.2%	8,000 EJ Conventional Oil 7,300 EJ Natural Gas Nuclear costs decline by 0.4% annually	Same as "a"	Same as "a"
IS92d	UN Medium-Low Case 6.4 B by 2100	1990-2025 1990-2100	2.7% 2.0%	Oil and gas same as "c" Solar costs fall to \$0.065/kWh 272 EJ of biofuels available at \$50/barrel	Emission controls extended worldwide for CO, NO_x, NMVOC and SO_x. Halt deforestation. Capture and use of emissions from coal mining and gas production and use.	CFC production phase out by 1997 for industrialized countries. Phase out of HCFCs.
IS92e	World Bank 1991 11.3 B by 2100	1990-2025 1990-2100	3.5% 3.0%	18,400 EJ conventional oil Gas same as "a" Phase out nuclear by 2075	Emission controls which increase fossil energy costs by 30%.	Same as "d"
IS92f	UN Medium-High Case 17.6 B by 2100	1990-2025: 1990-2100:	2.9% 2.3%	Oil and gas same as "e" Solar costs fall to \$0.083/kWh Nuclear costs increase to \$0.09/kWh	Same as "a"	Same as "a"

† - Approximate conversion factor: 1 barrel = 6GJ.

Table A3.2: Population assumptions (in millions).

Region	World Bank (1991) IS92a, b & e 1990	2025	2100	UN Med-Low IS92c & d 2025	2100 †	UN Med-High IS92f 2025	2100 †
OECD	838	939	903	865	503	1,039	1,359
USSR & E.-Europe	428	496	513	475	337	540	856
China & CP Asia ††	1,218	1,721	1,924	1,526	935	1,881	2,385
Middle East	128	327	603	272	223	349	693
Africa	648	1,587	2,962	1,375	1,668	1,807	4,651
Latin America	440	708	869	682	770	832	1,662
South & East Asia	1,553	2,636	3,538	2,395	1,979	2,999	5,987
Total	5,252	8,414	11,312	7,591	6,415	9,445	17,592

† Regional breakout of data for 2100 reported here was derived from UN Population Division (1992) which used different regions from this IPCC analysis and did not provide country-specific estimates.
†† CP = Centrally planned economies.

Table A3.3: GNP growth assumptions (average annual rate)

	World Bank† 1965 1989	World Bank† Low†† 1990 2000	World Bank† High†† 1990 2000	IS92c 1990 2025	IS92c 1990 2100	IS92a 1990 2025	IS92a 1990 2100	IS92e 1990 2025	IS92e 1990 2100
OECD	3.2%	2.4%	3.1%	1.8%	0.6%	2.5%	1.7%	3.0%	2.2%
USSR/E.Europe†††	1.3%	3.2%	3.6%	1.5%	0.5%	2.4%	1.6%	3.2%	2.4%
China & CP¥ Asia	7.6%	5.6%	6.7%	4.2%	2.5%	5.3%	3.9%	6.1%	4.7%
Other	4.7%	3.8%	4.5%	3.0%	2.1%	4.1%	3.3%	4.8%	4.1%
Global	-	-	-	2.0%	1.2%	2.9%	2.3%	3.5%	3.0%

† Source: World Bank (1991).
†† Estimated using projections of regional growth in GDP/capita and country estimates of GDP, population and population growth from 1990 to 2000.
††† World Bank data only include several countries in Eastern Europe.
¥ CP = Centrally planned economies.

and medium-high cases reach 6.4 billion and 17.6 billion, respectively, in 2100. Table A3.2 summarizes the population assumptions by region.

Future economic growth assumptions are summarized in Table A3.3. Growth rates assumed in this update are based in part on the reference scenario to 2025 of the Energy and Industry Sub-Group (EIS) of the RSWG (IPCC, 1991b). However, we have adjusted them downward in the near and medium terms in Eastern Europe, the (former) USSR, and the Persian Gulf due to the likely impacts of recent political events. Overall, the economic growth assumptions in IS92a and IS92b are higher than those used in the SA90, especially in Africa, China and Southeast Asia. However, the IS92a and b assumptions for 1990 to 2000 are generally below or at the low end of the ranges forecast by the World Bank (1991), with the exceptions of the US, OECD (Organization of Economic Cooperation and Development) Pacific and the Middle East. Table A3.3 compares the ranges of GNP assumptions in the new IPCC Scenarios with historical data and the near term projections from the World Bank (World Bank, 1991). The GNP growth rate assumptions for the initial 35 years of IS92a and b, from 1990 to 2025, are substantially below those experienced by most world regions in the past 34 years, from 1955 to 1989. The exceptions are Africa; and Eastern Europe and the USSR, where we assume substantial

Table A3.4: GDP per capita growth † from 1955 to 1989 (average annual rate)

OECD Members	2.9%
Eastern Europe	2.5%
Europe, Middle East, & North Africa	2.6%
Sub-Saharan Africa	1.0%
Latin America	1.6%
Asia	4.6%

† Source: World Bank (1991), rates of growth re-estimated.

Table A3.5: GNP per capita growth assumptions from 1990 to 2025 (average annual rate)

	IS92c	IS92a	IS92e
OECD	1.7%	2.2%	2.7%
USSR/E.-Europe	1.2%	2.0%	2.7%
China & CP Asia	3.5%	4.3%	5.1%
Mid-East	0.5%	1.2%	2.0%
Africa	0.9%	1.7%	2.5%
Latin America	1.2%	1.9%	2.7%
Rest of Asia	2.3%	3.0%	3.8%

structural adjustment would boost growth in the medium term. Over the long-term, GNP tends to slow due to an expected slowing of population growth.

Income per capita is assumed to rise most rapidly in the developing world throughout the next century, but in 2100 it remains well below levels in the developed economies. Table A3.4 provides historical data from the World Bank on growth of GDP/capita in the past 34 years, for comparison with Table A3.5 showing the range of IS92 assumptions for 1990 to 2025.

It is important to note that the emission results provided in this paper are highly sensitive to both the population and economic growth assumptions. These parameters would most likely be negatively correlated, however. The economic growth assumptions in IS92a and b fall below historical rates. It is uncertain whether ambitious growth can be realized and maintained in all regions, especially considering possible capital and resource constraints and the presently volatile circumstances in a number of nations. On the other hand, the relatively low GNP per capita in developing countries even at the end of the period suggest that the IS92a and b assumptions fall well below the aspirations of many countries.

All the scenarios presented here include the changes in government policies aimed at mitigating climate change which have been adopted (as of December 1991). The expert group used a rule for IS92a to incorporate only those emission controls internationally agreed upon and national policies enacted into law, such as the London Amendments to the Montreal Protocol, the amended US Clean Air Act, and the SO_x, NO_x, and VOC Protocols of the Convention on Long Range Transboundary Air Pollution (LRTAP).[1] It does not include the CO_2 emissions targets that have been proposed but not enacted by many OECD countries nor broad policy proposals to cut back on deforestation.

Another scenario, IS92b, shows some of the uncertainty surrounding these policies. IS92b enlarges the interpretation of current policies to include stated policies beyond those legally adopted. All CO_2 commitments of OECD countries, for example, are included, along with an assumption of worldwide ratification and compliance with the amended Montreal Protocol. Since we assume that the CO_2 stabilization commitments would be achieved through improvements in energy efficiency and switching from fossil fuels to nuclear or renewable energy, this reduces simultaneously some of the other greenhouse gases emitted by fossil fuels. We assume that after the target years, emissions would be kept level.

Four additional scenarios have been constructed to examine the sensitivity of future greenhouse gas emissions to a wider range of alternative input assumptions for key variables. Full documentation is available in Pepper *et al.* (1992). The scenarios suggest very different pictures of the future.

IS92c, the lowest scenario, assumes the UN medium-low population forecast, in which population declines in the twenty-first century. It also assumes lower growth in GNP per capita than IS92a and b, as well as low oil and gas resource availability, resulting in higher prices and promoting expansion of nuclear and renewable energy. Deforestation would be slower with lower population growth. IS92d represents another low but more optimistic scenario. It extrapolates some possible trends towards increasing environmental protection, but includes only actions that could be taken due to concern about local or regional air pollution, waste disposal, etc. Population growth assumes the UN medium-low forecast and would be associated with lower natality, falling below the replacement rate late in the twenty-first century, due for example to improvement in per capita income or increased

1- In addition, since there is a trend toward increasing control of local air pollution in many countries, all scenarios assumed a slow penetration of low-cost technologies which reduce SO_x and NO_x emissions from very large installations and, in the case of NO_x and CO, from motor vehicles.

Table A3.6: Selected results of six 1992 IPCC greenhouse gas scenarios.

Scenario	Years	Decline in TPER/GNP (AARC)	Decline in C Intensity (AARC)	Cumulative Net Fossil C Emissions (GtC)	Tropical Deforestation: Total Forest Cleared (million hectares)	Tropical Deforestation: Cumulative Net C Emissions (GtC)	Year	Emissions Per Year: CO_2 (GtC)	CH_4 (Tg)	N_2O (TgN)	CFCs (kt)	HCFCs (kt)	HFCs (kt)	Other halo-carbons (kt)	SO_x (TgS)
IS92a	1990-2025	0.8%	0.4%	285	678	42	1990	7.4	506	12.9	827	143	0	864	98
	1990-2100	1.0%	0.2%	1386	1447	77	2025	12.2	659	15.8	217	824	511	121	141
							2100	20.3	917	17.0	3	1074	1823	0	169
IS92b	1990-2025	0.9%	0.4%	275	678	42	2025	11.8	659	15.7	36	847	533	3	140
	1990-2100	1.0%	0.2%	1316	1447	77	2100	19.1	917	16.9	0	1075	1823	0	164
IS92c	1990-2025	0.6%	0.7%	228	675	42	2025	8.8	589	15.0	217	824	511	121	115
	1990-2100	0.7%	0.6%	672	1343	70	2100	4.6	546	13.7	3	1074	1823	0	77
IS92d	1990-2025	0.8%	0.9%	249	420	25	2025	9.3	584	15.1	24	316	1064	3	104
	1990-2100	0.8%	0.7%	908	651	30	2100	10.3	567	14.5	0	0	2764	0	87
IS92e	1990-2025	1.0%	0.2%	330	678	42	2025	15.1	692	16.3	24	316	1064	3	163
	1990-2100	1.1%	0.2%	2050	1447	77	2100	35.8	1072	19.1	0	0	2764	0	254
IS92f	1990-2025	0.8%	0.1%	311	725	46	2025	14.4	697	16.2	217	824	511	121	151
	1990-2100	1.0%	0.1%	1690	1686	93	2100	26.6	1168	19.0	3	1074	1823	0	204

TPER = Total Primary Energy Requirement
Carbon (C) intensity is defined as units of carbon per unit of TPER
AARC = Average annual rate of change
CFCs include CFC-11, CFC-12, CFC-113, CFC-114 and CFC-115
Other halocarbons include carbon tetrachloride, methyl chloroform, Halon 1211 and Halon 1301

family planning. Like IS92c, low fossil resource availability gives rise to greater market penetration of renewable energy and safe nuclear power. The costs of more stringent local pollution controls are incorporated into IS92d through a 30% environmental surcharge on fossil energy use. Greater well-being is assumed to lead to voluntary actions to halt deforestation, to adopt CFC substitutes with no radiative or other adverse effects, and to recover and efficiently use the CH_4 from coal mines and landfills.

IS92e, the case with the highest estimated CO_2 emissions, assumes the World Bank (moderate) population forecast but a more rapid improvement in GNP per capita. Fossil resources are plentiful, but, due to assumed improvement in living standards, environmental surcharges are imposed on their use. Nuclear energy is phased out by 2075. CFC substitute assumptions are like those in IS92d, but plentiful fossil resources discourage the additional use of coal mine methane for energy supply as assumed in IS92d. Deforestation proceeds at the same pace as in IS92a. IS92f falls below IS92e, using the high UN population growth forecasts but the lower assumptions of improvement in GNP per capita than IS92a. Other assumptions are high fossil resource availability, increasing costs of nuclear power, and less improvement in renewable energy technologies and costs. Table A3.6 summarizes key results of the scenarios for all gases and Figure A3.1 illustrates the scenarios for CO_2 emissions only. Table A3.7 summarizes net emissions of CO_2, and anthropogenic emissions of CH_4, and N_2O by region for IS92a.

A3.5 Comparisons with Other Studies

No systematic analysis has been conducted in this exercise of the likelihood of any of the outcomes illustrated in the six new IPCC Scenarios described above. However, the probabilities of these emission paths has been considered in part by comparison with other studies of probabilities

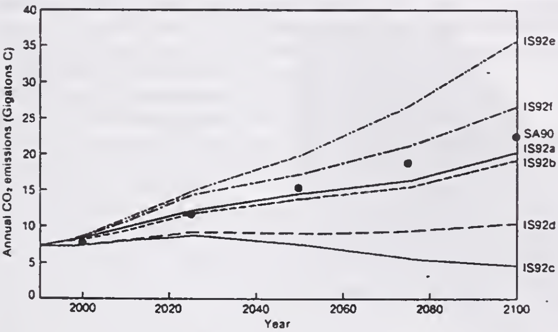

Figure A3.1: Annual CO_2 emissions from energy, cement production and tropical deforestation for the six IPCC 1992 scenarios (IS92a-f) and for the 1990 IPCC Scenario A (SA90).

Table A3.7: Net emissions of CO_2 and anthropogenic emissions of CH_4 and N_2O under IS92a.

	CO_2 (GtC)			Anthropogenic N_2O (TgN)			Anthropogenic CH_4† (Tg)		
	1990	2025	2100	1990	2025	2100	1900	2025	2100
OECD	2.8	3.5	4.3	1.4	2.0	1.7	74	90	143
USSR & Eastern Europe	1.7	2.4	2.5	0.8	1.0	0.9	70	62	113
China and CP Asia††	0.6	1.6	4.2	0.5	0.8	0.9	37	53	73
Other	0.9	3.2	8.8	1.9	3.7	5.1	146	260	380
Total	6.0	10.7	19.8	4.6	7.5	8.7	326	465	709

† Excludes CH_4 from domestic sewage which was not estimated on a regional basis.
†† CP = Centrally planned economies.

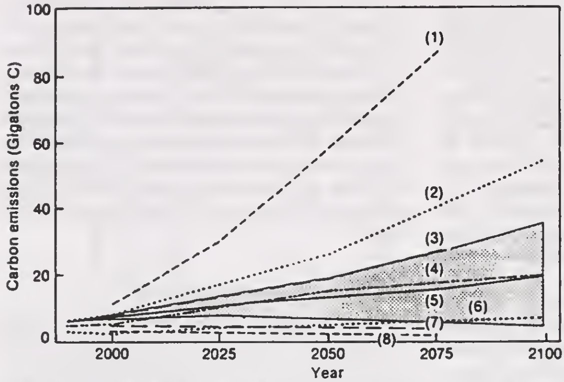

Figure A3.2: Uncertainty analyses for carbon emissions from fossil fuel. The following studies are represented: Edmonds - (1) 95th percentile, (3) 75th percentile, (7) 25th percentile, and (8) 5th percentile; Nordhaus and Yohe - (2) 95th percentile, (4) 50th percentile, and (6) 5th percentile; also (5) IS92a. The shaded area indicates the range of the IS92 scenarios.

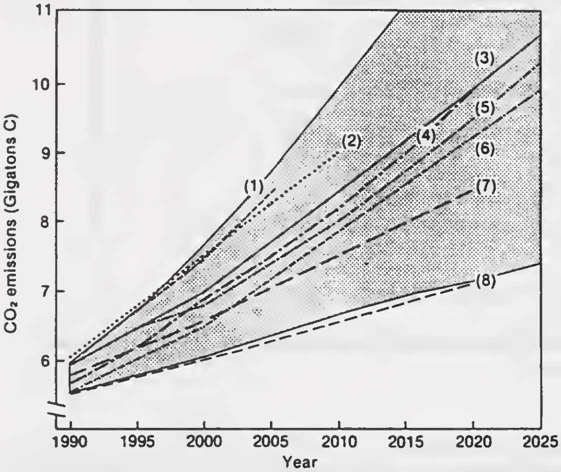

Figure A3.3: Comparison of CO_2 emissions from fossil fuels out to AD 2025 according to: (1) IEA; (2) CEC; (3) IS92a; (4) OECD; (5) IS92b; (6) SA90; (7) the World Energy Conference (WEC) "moderate" and (8) "low" scenarios. The shaded area indicates the range of the IS92 scenarios.

and "best guess" scenarios. Two studies, Edmonds *et al.* (1986) and Nordhaus and Yohe (1983) explicitly examined the issue of uncertainty by estimating the probabilities associated with the various critical input assumptions and the correlation among them, in order to calculate probability distributions of future CO_2 trends. Figure A3.2 shows their results, against a shaded area representing the range of the new IPCC Scenarios. Both the Edmonds *et al.* and the Nordhaus and Yohe teams found a very wide variation in potential future emissions in the absence of policies to limit this growth. The IS92a falls slightly below the 50th percentile values from Nordhaus and Yohe in the 2050 to 2100 time period until they coincide near 2100. IS92b is slightly lower. The IS92a and b lie between the

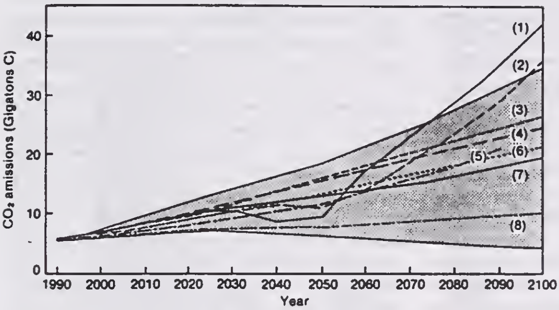

Figure A3.4: Comparison of CO_2 emissions from fossil fuels according to longer-range scenarios: (1) CETA; (2) CRTM-RD; (3) Manne & Richels; (4) EPA (RCW); (5) Edmonds/Reilly; (6) SA90; (7) IS92a, and (8) EPA (SCW). The shaded area indicates the range of the IS92 scenarios.

50th and 75th percentiles in the Edmonds analysis. The highest, new IPCC Scenario is very close to Edmonds 75th percentile, while the lowest is higher than Edmonds 25th percentile. These results from Edmonds *et al.* and Nordhaus and Yohe reinforce the conclusion that emission trajectories are extremely sensitive to a number of key parameters including population growth, economic growth, improvements in energy efficiency and structural change in the economy, as well as the future costs of fossil energy and alternative energy supplies.

Figure A3.3 compares CO_2 emissions from the range of IS92 scenarios in the period 1990 to 2025 to emissions adapted from scenarios of future energy use developed by the International Energy Agency (IEA, 1991), the Commission of the European Communities (CEC, 1989), the World Energy Conference (WEC, 1989), Burniaux *et al.* (1991), and SA90. Emissions in the IEA and CEC Scenarios are from 5% to 12% higher than the emissions in the IS92a through to 2010, the end point of their scenarios. Burniaux *et al.* (1991), using the OECD-GREEN model, suggest CO_2 emissions that are 4% lower than the IS92a in the early years but increase to the same levels by 2020. Emissions in the WEC moderate scenario are 24% lower than IS92a in 2020. Figure A3.4 examines longer-term scenarios, comparing the new IPCC Scenarios with 7 others, including the SA90 Scenario, two scenarios (Slowly Changing World, SCW, and Rapidly Changing World, RCW) developed by the US EPA (1990), scenarios from Manne and Richels (1990), and several studies underway within the Stanford University Energy Modeling Forum. The modellers include Edmonds and Barnes, Peck and Teisberg (using CETA), and Rutherford (using CRTM) (Weyant, 1991: studies to be published in mid-1992). The range of the new IPCC Scenarios is broader than the "central tendency" studies presented in Figures A3.3 and A3.4. This is especially true by 2100, due to the range of population and economic growth assumptions used in the scenarios. Edmonds *et al.* (1992) provides a more detailed comparison of these scenarios.

A3.6 Energy

Future levels of greenhouse gas emissions from the energy sector are a function primarily of population, incomes, the structure and efficiency of economies, and the relative costs and availability of different sources of energy. The population and economic assumptions in this update of the IPCC scenarios have already been discussed. To 2025, the estimates of energy demand by region and sector are based primarily on the EIS reference scenario. After 2025, energy demand is a function of the economic assumptions and the factors discussed in this Section, and modelled by the ASF (EPA, 1990). Associated emissions of greenhouse gases are estimated using coefficients from the OECD (1991).

The exogenous assumptions of improvements in the intensity of energy end-use are critical parameters counterweighing the upward push on CO_2 emissions from population and economic growth. The assumptions used within IS92a and b result in a global decrease in energy intensity of 0.8% annually in the period to 2025, and 1.0% annually from 2025 to 2100. The decrease in energy per unit of GNP is assumed to be particularly strong in China through to 2100 and in Eastern Europe and the former republics of the Soviet Union in the period 2000 to 2025 as IS92a and b assume substantial structural change. This reflects a complex mix of factors, including market-oriented reforms, a tendency to increase energy demand per capita with increased standards of living (though GNP growth is substantially reduced in Eastern Europe and the use of non-fossil energy sources yield reductions in this growth to an annual average of 0.2%. Emissions from developing economies continue to rise due to increases in population and economic growth. In the period, 1990 to 2100, CO_2 emissions per capita from energy use grow at an average annual rate of only 0.2% to 0.3% in the OECD, Eastern Europe, and the republics of the former Soviet Union, while averaging 1.0% for the rest of the world. CO_2 emissions per capita in developing countries remain on average one quarter to one half those of developed countries by 2100. Conversely, CO_2 emissions per dollar GNP (per $GNP) in the OECD are two thirds the global average, one half those of Eastern Europe and the former Soviet Union, and one fifth those of China. Global average CO_2 emissions per $GNP decline at an average annual rate of 1.2% from 1990 to 2100. Regionally, the highest rate of decline is in China where CO_2 emissions per $GNP are over four times higher than the global average in 1990.

IS92b incorporates the stabilization goal for fossil carbon dioxide emissions for the year 2000, proposed by many OECD Member countries. If countries achieve these commitments and sustain them through 2100 (which is likely to require programmes beyond those already planned) and the rest of the world does not adopt similar measures, global emissions in 2025 of fossil carbon would be 0.4 GtC lower than in the IS92a. This reduction represents a reduction of 11% in emissions of CO_2 from the OECD from IS92a but only a 4% reduction of global emissions. These results reflect the long-term contribution of the economies of developing countries, the republics of the former Soviet Union, and Eastern Europe to CO_2 emissions.

A3.7 Halocarbons

Halocarbons, including chlorofluorocarbons (CFCs), their substitutes, and other compounds which deplete stratospheric ozone, may have important implications for climate change. Many of these compounds exert a much more powerful direct radiative forcing than CO_2 per molecule. Recently, it has been discovered that the loss of lower-stratospheric ozone can reduce the radiative forcing of the troposphere/surface system, particularly at high latitudes. Hence, ozone depleting molecules can have both positive (direct) and negative (indirect) contributions to radiative forcing. However, the net effect of such halocarbons on globally averaged temperatures or, more broadly, on climate is uncertain at present. As a result, the comparisons of scenarios for these gases are summarized using the kilotons (kt) of the compounds, not the index of direct "Global Warming Potential" (GWP), as calculated in Section A2 of this report.

An important event since the development of the scenarios for the first IPCC assessment is the agreement to adjust and amend the Montreal Protocol in London in 1990 (the "London Amendments"). Most key nations have either now signed the agreement or have pronounced the intention to do so. In IS92a, 70% of the developing world is assumed to ratify and comply with the London Amendments. This percentage is based on the GNP of countries that have signed and/or ratified as of December 1, 1991 (e.g., China has signed while India has not). We further assume in IS92a that if most of the world develops and uses CFC substitutes, then the need to trade in global markets and "technology transfer" will lead to a gradual phase-out of all CFC use (we assume gradually from 2025 to 2075) even without worldwide ratification. We have also included the voluntary reductions ahead of schedule achieved by many countries. IS92b assumes global compliance with the Montreal Protocol.

The London Amendments contain a recommendation only to use halocarbon substitutes for a transition period. There are no international agreements for eventually phasing down the production of all substitute compounds. Some substitutes may not deplete stratospheric ozone but may still contribute to climate change. Therefore, in the scenarios, we assume that the production of substitutes would mimic the growth rate of the underlying controlled compounds which they replace under the phase-out, adjusted for market reductions due to non-chemical substitution and increased use of recycling and other emission control programmes. Accordingly, all of the cases assume that the demand for CFCs grows by 2.5% annually until 2050 then remains flat. HCFCs and HFCs are assumed to replace approximately 21 to 42% (depending on the scenario) of phased-out CFCs. Substitution is weighted much more towards HCFCs than HFCs over the long-term unless additional policy steps are taken.

This analysis includes seven cases of future emissions of CFCs and their substitutes. Three of these cases are incorporated into the IS92 Scenarios. The first two cases, "Partial Compliance and High HCFC" and "Partial Compliance and Reduced HCFC" portray a future where only 70% of the developing world ratifies and complies with the London Amendments. In these scenarios, CFC production in the remaining 30% continue to grow until 2100. Also, the HCFC reductions in the US are not incorporated. The third scenario, "Partial Compliance and Technology Transfer", is incorporated into IPCC Scenarios IS92a, c, and f. It assumes partial compliance with the London Amendments but assumes that "technology transfer" results in a full phase-out of production of CFCs by 2075. It includes the phase-out of HCFCs in the US required by the Clean Air Act. The fourth case, "Global Compliance", is incorporated in IS92b and contains full global ratification and compliance with the London Amendments. The fifth case, "97 Phase-Out for Developed Countries", accelerates the phase-out schedule for CFCs.

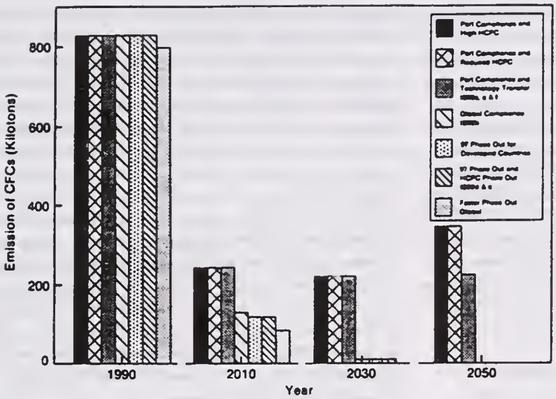

Figure A3.5: Emission of chlorofluorocarbons (CFCs) under a range of scenarios. Includes CFC-11, CFC-12, CFC-113, CFC-114 and CFC-115.

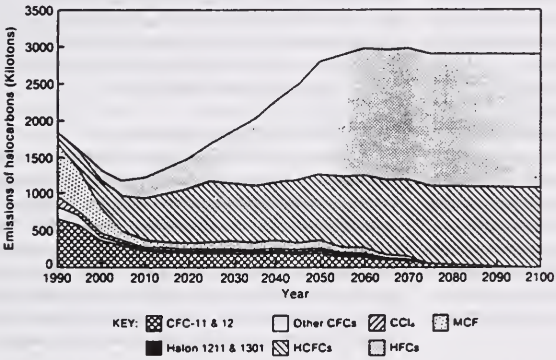

Figure A3.6: Emission of halocarbons under IS92a, c and f. These assume only partial compliance with the London Amendments to the Montreal Protocol but, through technical transfer to non-complying countries, a complete end to CFC production by AD 2075.

The sixth case, "97 Phase-Out and HCFC Phase-Out" is incorporated in IS92c and d and expands on the fifth case by incorporating a global phase-out of HCFCs. The seventh case, "Faster Phase-Out - Global", accelerates the phase-out of CFCs and HCFCs in developing countries.

For the calculations, US EPA's Integrated Assessment Model for CFCs was used. Detailed results can be found in the supporting document, Pepper *et al.* (1992). In the IS92a, emissions of CFCs, carbon tetrachloride, and methyl chloroform decline rapidly through 2010 (see Figures A3.5 and A3.6, "Partial Compliance and Technology Transfer Case"). After 2010, these emissions stabilize and ultimately decline to zero after 2075 as all the world adopts the prominent technologies. Emissions of HCFCs and HFCs grow rapidly throughout the whole time horizon in all cases, reflecting their roles as substitutes for the CFCs and the postulation of no controls on their emissions (except on HCFCs in the US). Its results indicate that the composition of substitutes could have an important impact on levels of radiative forcing.

If "technology transfer" to non-signatories of the agreement were not to lead to a phase-out of CFCs, the implications by 2100 could be substantial, leading to emissions almost back up to the level estimated for 2000.

The results for the emissions of CFCs are depicted, as an example, in the "Partial Compliance and High HCFC" case in Figure A3.5. In this case, after 2010, emissions of CFCs, carbon tetrachloride and methyl chloroform stabilize and then start to increase. This reflects growth from non-signatories of the London Amendments.

IS92b assumes full ratification of and compliance with the London Amendments. Emissions are nearly eliminated much earlier ("London Amendments-Global Compliance") than in IS92a. Moreover, recent data showing more severe ozone depletion (WMO, 1992) could lead to a more rapid phase-out of CFCs and halons, carbon tetrachloride, and methyl chloroform ("97 Phase-Out for Developed Countries"). Controls on the use of HCFCs are also possible.

A3.8 Agriculture, Forests and Land Conversion

A3.8.1 Agriculture

Details of the estimation of greenhouse gases from agricultural sources are available in Pepper *et al.* (1992). The distribution of the global emissions of non-CO_2 greenhouse gases among different sources in the base year has been taken from the assessment of the global budgets reported in Section A1 of this document. This distribution is still poorly understood for most gases. In particular, emissions of CH_4 from rice cultivation are highly uncertain but lower than believed in IPCC (1990). Average emission coefficients of 38 grams per square metre per year for land under rice cultivation have been selected for all scenarios based on the CH_4 emission budget of 60 teragrams (Tg). In IS92a and b, the emissions rise gradually from 60Tg in 1990 to 88Tg by 2050, then decline to 84Tg by 2100. The scenarios assume continuing advances in crop yields which average 0.5% annually over the period. Consequently, the growth in emissions is slower than growth in rice production, which more than doubles.

In IS92a and b, CH_4 emissions from enteric fermentation in domestic animals rise from 84Tg in 1990 to close to 200Tg by 2100. This increase reflects a rapid increase in consumption of meat and dairy products and assumes constant emissions per unit of production. Emissions of CH_4 from animal wastes have been added, changing with the levels of meat and dairy production. If meat production per animal were to increase, emissions would be lower. Emissions from animal wastes increase from 26Tg CH_4 in 1990 to 62Tg CH_4 by 2100. It is uncertain whether this growth in the production of meat and dairy products can actually be maintained, taking into account possible land and feed constraints which are not explicitly dealt with in these scenarios. Autonomous developments that affect the emissions from enteric fermentation or animal waste per unit of production, such as those resulting from changed feeding patterns, are not hypothesized either. Both types of factors could change the emission trends of these scenarios.

Emissions of N_2O from fertilized soils in 1990 of 2.2 TgN have been selected as the starting budget, falling within the range of uncertainty of 0.3 to 3.0 TgN reported in Section A1. They increase in proportion to fertilizer use, which more than doubles in IS92a and b. The impact of changing fertilization practices and the dependency of N_2O emissions on local soil types, moisture, agricultural practices, etc., has not been estimated.

A3.8.2 Forests and Land Conversion

Since SA90 was finalized, new data have become available regarding both tropical deforestation rates and the average content of carbon per hectare of above-ground vegetation. Both are higher than the assumptions used in SA90. The estimates of carbon in soils and fluxes of greenhouse gases with changes in land uses remain as in SA90. Neither of the possible effects on CO_2 fluxes due to increased fertilization or respiration, which may be associated with higher CO_2 atmospheric concentrations or temperature

Table A3.8: Assumptions used in deforestation cases.

Scenario Used In	Biomass Content	Rate of Deforestation
IS92a, b, & e	Moderate	Moderate (tied to moderate population growth)
IS92c	Moderate	Moderate (tied to low population growth)
IS92d	Moderate	Halt Tropical Deforestation
IS92f	Moderate	Moderate (tied to high population growth)
None	High	Moderate (tied to moderate population growth)
None	Moderate	High
None	High	High
None	Moderate	Halt Tropical Deforestation/Increase Establishment of Plantations

increases, have been incorporated in this analysis.

To incorporate the new data and the uncertainties still surrounding these parameters, eight cases of tropical forest clearing and emissions of greenhouse gases were developed. These eight cases include four cases which were incorporated within the new IPCC Scenarios which assume moderate assumptions of rates of tropical deforestation (except IS92d which has a halt to deforestation) and biomass content of vegetation in these forests. The eight cases also include four sensitivities around the case incorporated in IS92a. The sensitivity cases vary rates of deforestation, rates of establishment of plantations, and assumptions concerning the biomass content of the forests. Table A3.8 summarizes these cases and their assumptions.

As lands convert from one use to another, greenhouse gases can be released or taken up by vegetation and soils, for example by the burning or regrowth of forests or the tilling or amendment of soils. This analysis simulates and tracks the changes of land parcels from one use to another from 1975 to 2100, due to agricultural demand, burning, plantations, etc., and calculates the associated greenhouse gas emissions and uptake over time. As land is cleared, sometimes more than once in the period of analysis, only part of the carbon stored in vegetation and soils is released over an extended period of time. As regrowth occurs on cleared land, carbon is sequestered. We calculate the net balance of carbon from vegetation and soils of all lands estimated to be tropical forests at any time from 1975 through 2100. Assumptions about rates of carbon loss or absorption and other parameters used in this analysis, as well as the case results, are detailed in Pepper *et al.* (1992).

The IS92 Scenarios use the new FAO 1990 Tropical Forest Assessment (FAO, 1991) and the 1988 update of the 1980 Tropical Forest Assessment (FAO, 1988) for its deforestation rates. The new assessment estimates that, on average, 17 million hectares of tropical closed and open forest were cleared annually from 1981 to 1990. The 1988 FAO Tropical Forest Assessment provided estimates of clearing rates for the period 1976 to 1980. While questions have been raised concerning the reliability of these data, they are the best and most recent currently available for the world.

We estimated a constant rate of change in clearing rates over this period such that the average quantities of clearing for 1976 to 1980 and for 1981 to 1990 match those reported in the FAO 1988 and 1991 reports, respectively. Moreover, this estimate is constrained so that forest areas in 1980 equal the quantities given in the more complete and detailed 1980 assessment. This results in calculated clearing rates increasing from 13.2 million hectares in 1980 to 19.3 million hectares in 1990. After 1990, deforestation rates increase in proportion to population, but lagged twenty years and constrained by available forest area in each country. In the "high deforestation" sensitivity cases, these rates are increased by an additional 1% point per year. In the "halt deforestation" sensitivity case and in IS92d, we assume that rates of deforestation decline, starting in 1990. The IPCC Greenhouse Gas Task Force advised that it should be assumed that all forests not legally protected, including areas which have been classified as non-productive, can be subject to deforestation (IPCC, 1991c).

Forest clearing in IS92a, b, c, e, and f increases to 20 to 23.6 million hectares per year by 2025, depending on population growth, and then declines. In IS92d, clearing declines steadily after 1990 to 0.7 million hectares per year by 2025. In the high deforestation sensitivity cases, tropical forest clearing increases to 28.6 million hectares in 2025 before declining. In all sets of assumptions, available forest resources within each country provide upper bounds on future clearing. In the IS92a, 73% of all tropical forests (1.4 billion hectares), are cleared by 2100. In the high deforestation sensitivity case, this fraction increases to 91%. In IS92a, countries representing 43% of forest clearing in 1980 have (or have nearly) exhausted their forest resources by 2025. By 2050, this fraction increases to 52%.

Other factors which vary in the sensitivity cases include the fate of forest fallow, future rates of plantation establishment, and the carbon stored in the aboveground biomass. The high deforestation sensitivity cases include another possible net source of carbon: permanent clearing of forest fallow. These are areas of logged or abandoned agricultural lands which are regenerating to forest. The high deforestation sensitivity cases assume that up to 10 million hectares of forest fallow are currently being converted to permanent agriculture annually (Houghton, 1991) and that this clearing continues into the future until almost all forest fallow is converted. In IS92a, the establishment of plantations, which FAO (1988) estimates as 1.3 million hectares annually between 1980 and 1985, is assumed to continue with 118 million hectares added between 1990 and 2100. The high deforestation sensitivity cases assume that no new plantations are added after 1990.

Moderate estimates of carbon stored in the biomass are from OECD (1991) which have been adapted from Brown and Lugo (1984), Brown *et al.* (1989), and Brown (1991), and have been estimated using wood volumes. The moderate biomass estimates are used for the IS92 Scenarios. The high biomass estimates, used in the sensitivity analyses, increase the moderate estimates by the percentage corrections cited in Houghton (1991) to reflect uncertainties in measurement techniques and results from other studies utilizing alternative (i.e., destructive sampling) approaches. Table A3.9 summarizes current estimates of biomass contents and those used in all IS92 scenarios.

***Table A3.9:** Carbon stored in tropical forests (tons C/hectare).*

	IS92 a,b †††				Carbon Stocks from Houghton (1991)				
					Earlier Estimate †		Recent Estimate ††		
	Closed B-leaf	Closed Conif.	Open B-leaf	Crops	Moist Forest (D/V)†	Seasonal Forest (D/V)†	Closed Forest (U/L)††	Open Forest (D/V)†	Crops
Vegetation									
Latin America	76	78	27	5	176/82	158/85	89/73	27/27	5
Asia	97	83	27	5	250/135	150/90	112/60	60/40	5
Africa	117	68	16	5	210/124	160/62	136/111	90/15	5
Soils	100	100	69	-	100	90	-	50	-

† For columns labelled (D/V), the first value is based on destructive sampling of biomass and the second value is calculated from estimates of wood volumes.
†† For columns labelled (U/L), the first value is for undisturbed forests and the second value is for logged forests.
††† Source: OECD (1991).

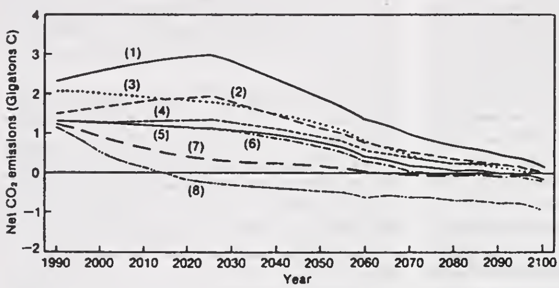

Figure A3.7: Comparison of net CO_2 emissions from tropical deforestation according to some longer-range scenarios: (1) High deforestation/high biomass; (2) High deforestation/moderate biomass; (3) moderate deforestation/high biomass; (4) IS92f; (5) IS92a, b and e - moderate deforestation/moderate biomass; (6) IS92c; (7) IS92d, and (8) No deforestation/high plantation. *(Note: does not include the effects of fertilization or increased respiration on net CO_2 emissions due to higher CO_2 atmospheric concentrations.)*

CO_2 emissions in the IS92 Scenarios and the sensitivity cases range from 1.1 GtC to 2.3 GtC in 1990. These include net soil carbon released as well. In the IS92a, emissions are relatively flat through to 1995 and then start to decline. Net emissions are slightly negative by 2100 due to carbon sequestration by plantations. In the high deforestation and high biomass sensitivity case, emissions increase to 3.0 GtC by 2025, decline to 1.9 GtC in 2050 and 0.2 GtC by 2100. Even though in all of the cases clearing of open forests in the period 1980 to 1990 represents over one third of total clearing, net emissions of CO_2 from open forests represent less than 10% of total deforestation emissions.

All these cases do not span the range of possibilities for both current and future emissions. There is a strong need for improvement of the base data. Moreover, current trends in deforested area, combined with changes in policies, could very well lead to emissions lower than in the moderate case.

In conclusion, the sensitivity analysis explores a wide range of possible futures and identifies the importance of several key assumptions. Figure A3.7 illustrates the CO_2 emissions from the IS92 Scenarios along with the sensitivities around IS92a. One sensitivity case, "High Deforestation/Moderate Biomass" illustrates the impact of the higher clearing rates and forest fallow clearing assumptions on CO_2 emissions. The sensitivity case, "Moderate Deforestation/High Biomass", illustrates the importance of assumptions concerning carbon stored within the biomass. The sensitivity case, "High Deforestation/High Biomass" shows the combined impact of these alternative assumptions. The "Halt Deforestation/ High Plantations" sensitivity case illustrates the potential for reducing emissions by quickly stopping forest clearing and actively establishing plantations. In this case, forest clearing is reduced starting in 1991 and eliminated by 2025. Up to 293 million hectares of plantations are established by 2100.

A3.8.3 Resolution of Land Assumptions

While these cases and sensitivities provide a plausible range of emissions they do not address all of the uncertainty. A key concern with these cases is consistency of the assumptions about land uses among the different sectors. Because the models and methodologies used for the different sectors are not fully integrated with respect to land use, this consistency is not automatically guaranteed. With population doubling by 2100, improved nutrition in the developing economies, and the agricultural land base possibly degraded, the demand for additional land conversion to produce crops especially in the developing countries would be significant, even if sustained productivity increases were achieved. Above, we already noted the anticipated demand for land for livestock and feed production, while the IS92a assumes over 190 EJ of energy from commercial biofuels by 2100, of which 70% would be in developing countries.

A review of current land uses, forest clearing, and plantation assumptions suggests that the assumptions in the new IPCC Scenarios are not inconsistent. FAO (1986) reported that in 1984, 1.5 billion hectares were used for arable land and permanent crops and 3.1 billion hectares were used for permanent pasture leaving 4.1 billion hectares of forest and woodlands. The moderate deforestation case assumes that on average 1.6 billion hectares of tropical forests will be cleared by 2100 while 0.1 billion hectares of forest plantations will be established, roughly allowing for a doubling of the arable land base. Table A3.10 summarizes these statistics for Latin America, Africa, and the Far East along with the IS92a assumptions for these regions. Clearing of forest land in these tropical regions matches well with the increase in population and demand for food. The largest concern would be in Asia where population densities are the highest and cleared forest lands might not have the same productivity as existing cropland, nor may the production be as sustainable. Any reduction in deforestation would reduce the potential land base and would have to be matched by increased productivity on existing agricultural land. Other anthropogenic influences on the terrestrial carbon cycle, such as pollution, erosion, desertification, logging in temperate and boreal zones and carbon sequestration in managed forests, have not been taken into account in this study because of the absence of quantitative information.

A3.9 Other Sectors and Gases

The 1992 Scenarios include emissions of additional gases and emissions from additional sectors. Specifically, emissions of N_2O, CH_4, CO, and NO_x from energy combustion and production were developed using assumptions about emission controls consistent with the US Clean Air Act and the Protocols under the Convention on Long-Range Transboundary Air Pollution. In the base year's emission budget, our estimate of emissions of CO from fossil fuels, by applying emission coefficients to fuel use, falls below the low end of the range given in Section A1 of this report. Our estimate of emissions reflects the latest data on energy consumption and emission coefficients, but the CO budget discrepancies need to be investigated further. Emissions of N_2O from the production of nitric and adipic acid have been included and reflect scenario assumptions on nitrogen fertilizer production and economic growth respectively. Emissions

Table A3.10: Land-use assumptions (10^6 hectares).

	Africa	Asia †	Latin America
FAO			
1984 Arable Land & Permanent Crops	154	272	177
1984 Permanent Pasture	630	35	551
Remaining Tropical Forest (1980)	704	431	938
Forest Cleared (1980-2100)	653	329	635
Plantation Area Established (1980-2100)	27	47	44
Maximum Energy Plantation Area††	88	101	118

† Far East as defined by FAO

†† Energy plantation area in addition to other plantation area

Table A3.11: Global emissions of direct greenhouse gases under IS92a.

	1990	2000	2025	2050	2100
CO_2 (GtC)					
Energy	6.0	7.0	10.7	13.2	19.8
Deforestation	1.3	1.3	1.1	0.8	-0.1
Cement	0.2	0.2	0.4	0.5	0.6
Total	7.4	8.4	12.2	14.5	20.3
CH_4 (Tg)					
Energy Production & Use	91	94	110	140	222
Enteric Fermentation	84	99	138	173	198
Rice	60	66	78	87	84
Animal Wastes	26	31	43	54	62
Landfills	38	42	63	93	109
Biomass Burning	28	29	32	34	33
Domestic Sewage	25	29	40	47	53
Natural	155	155	155	155	155
Total	506	545	659	785	917
N_2O (Tg N)					
Energy	0.4	0.5	0.7	0.8	0.8
Fertilized Soils	2.2	2.7	3.8	4.2	4.5
Land Clearing	0.8	0.8	1.0	1.1	1.0
Adipic Acid	0.5	0.6	0.9	1.1	1.2
Nitric Acid	0.2	0.3	0.4	0.5	0.5
Biomass Burning	0.5	0.6	0.7	0.7	0.7
Natural	8.3	8.3	8.3	8.3	8.3
Total	12.9	13.8	15.8	16.6	17.0
Halocarbons (kilotons)					
CFC-11	298	168	94	85	2
CFC-12	363	200	98	110	1
CFC-113	147	29	21	24	0
CFC-114	13	4	3	3	0
CFC-115	7	5	1	1	0
CCl_4	119	34	19	21	0
Methyl chloroform	738	353	97	110	0
HCFC-22	138	275	530	523	614
HCFC-123	0	44	159	214	267
HCFC-124	0	7	11	15	16
HCFC-141b	0	24	82	110	138
HCFC-142b	0	7	11	0	0
HCFC-225	5	17	30	38	40
HFC-134a	0	148	467	918	1055
HFC-125	0	0	14	175	199
HFC-152a	0	0	30	448	570

***Table A3.12:** Global emissions of indirect greenhouse gases under IS92a.*

	1990	2000	2025	2050	2100
CO (TgC)					
Energy	130	140	160	219	385
Biomass Burning	297	309	341	363	353
Plants	43	43	43	43	43
Oceans	17	17	17	17	17
Wildfires	13	13	13	13	13
Total	499	522	574	655	811
NO_x (TgN)					
Energy	25	28	43	53	72
Biomass Burning	9	9	10	11	11
Natural Lands	12	12	12	12	12
Lightning	9	9	9	9	9
Total	55	58	74	85	104
VOC Emissions by Gas (Tg)					
Paraffins	56	59	84	106	152
Olefins	42	43	49	56	72
Aromatics (btx) †	15	16	21	25	36
Other	8	8	12	15	23
Total	121	126	166	202	283
VOC Emissions by Sector (Tg)					
Energy Production & Use	27	30	48	64	102
Biomass Burning	53	53	54	54	52
Industry	23	25	36	46	62
Other	18	19	27	38	67
Total	121	126	166	202	283
Sulphur (TgS)					
Energy Production & Use	65	67	101	132	123
Biomass Burning	2	2	3	3	3
Other Industrial	8	10	16	19	21
Natural	22	22	22	22	22
Total	98	101	141	175	169

† Benzene, toulene, and xylene

of CO_2 from cement production and CH_4 from landfills reflect regional population and economic growth assumptions as well as expectations of resource limitations and saturation. Emissions of N_2O, CH_4, CO, and NO_x from biomass burning are based on emission coefficients from Crutzen and Andreae (1990) and Andreae (1991), and future rates of deforestation, clearing of fallow lands for shifting agriculture, non-commercial biofuel use, and other burning activities. Emissions of volatile organic compounds (VOCs) are highly uncertain, especially for developing countries. They are based on a detailed, country level emissions inventory developed by EPA (1991). They are compared with other sources and extended into the future based on activities such as transportation energy use, deforestation and biomass burning, and industrial activity. Emissions of SO_x from energy use are based on a study performed by Spiro *et al.* (1991) where emissions reflect average sulphur content of the different fossil fuels and are adjusted for emission control programmes. Emissions of all trace gases by gas and sector are summarized in Tables A3.11 and A3.12.

All of the new IPCC Scenarios except for IS92d show significant increases in emissions of CO, NO_x and SO_x even the assumed of adoption of some emission controls on large stationary sources and mobile sources in the developing countries. Emissions of these gases could be significantly higher if we had not assumed significant penetration of local pollution controls. For example, in IS92a annual emissions of CO grow from 499 TgC in 1990 to 811 TgC by 2100 and annual emissions of NO_x grow from 55 TgN in 1990 to 104 TgN by 2100. Without the assumed pollution controls, annual emissions of CO and NO_x would increase to 1049 TgN and 108 TgN, respectively, by 2100.

A3.10 Conclusions

This chapter presents a new set of IPCC greenhouse gas emission scenarios. The purpose is not to predict which evolution of greenhouse gases is most probable among the array of plausible alternatives. Rather, comparison of alternatives may help policy-makers to consider the directions in which future emissions may evolve in the absence of new greenhouse gas reduction efforts, and the types of change in important parameters which could or would have to occur to significantly change future paths. Commitments by individual governments or companies to reduce emissions of greenhouse gases in response to the global warming or other environmental issues could significantly affect some of the individual emission sources. However, it is difficult to take these commitments into account in global emission estimates.

Two of the Scenarios "IS92a" and "IS92b" update the original Scenario A from IPCC (1990) by incorporating important information which has become available in 1990 and 1991. IS92a includes only those policies affecting greenhouse gas emissions which are agreed internationally or enacted into national laws (as of December 1991). IS92b includes proposed greenhouse gas policies as well. While some of the revisions to the assumptions used in SA90 are significant, the results of IS92a and b are on balance very similar to the original SA90. The other scenarios provided in this chapter explore a broader range of plausible assumptions than in SA90, and indicate that the array of possible future trends in greenhouse gas emissions spans an order of magnitude. That the different futures within this range are not all equally probable has not been systematically addressed in this analysis, but this topic should be pursued. A more thorough exploration of the uncertainties in assumptions and relationships among parameters could reveal more about the confidence policymakers should have in such emission scenarios and in the influence of their decisions on future emission paths.

Even with a wide range of possible greenhouse gas scenarios, a number of conclusions can be drawn from the analysis:

- CFC emissions are likely to be substantially lower than previously estimated by the IPCC, especially if technology transfer and world trade requirements lead all countries to comply with the London Amendments to the Montreal Protocol. However, the future production and composition of CFC substitutes could significantly affect the levels of radiative forcing from halocarbons.

- The commitments by many OECD Member countries to achieve and maintain stabilization or reduction of their CO_2 emissions by the year 2000, in absolute terms or per capita, could have an important impact on their own emissions but a small influence on global emissions by the year 2100. The CO_2 commitments may have the simultaneous effect of reducing other greenhouse gases as well. Most of the uncertainty over future growth in greenhouse gas emissions is likely to depend on how developing countries, Eastern European countries, and republics of the former Soviet Union choose to meet their economic and social needs.

- Population growth, robust economic growth, plentiful fossil fuels at relatively low costs, and net deforestation tend to push upward the trends in greenhouse gas emissions; decreases in energy required per unit of GNP, the economical availability of renewable energy supplies, plantations of biomass, the control of conventional air pollution, and improvements in agricultural productivity tend to diminish greenhouse gas emissions over the long-term. Public attitudes and governmental policies may have a strong influence on which of these variables will dominate over the coming century.

- CO_2 emissions from forest and land conversion are higher than previous estimates, ranging from 1.1 GtC to 2.3 GtC in 1990, because of higher recent estimates of both deforestation rates and biomass in forests in the tropics, as assessed by the FAO and several recent studies, respectively.

- There is no evidence to alter the main conclusions of IPCC (1990) regarding CO_2 emissions from fossil fuels. While several factors could lead to both higher or lower emissions, especially in the long-term, most expert analyses suggest that these emissions could rise substantially over the coming century. IS92a and b, which most resemble the SA90 in terms of assumptions for key parameters, show a range of emissions of 10.3 to 10.7 GtC in 2025, and 18.6 to 19.8 GtC in 2100. However, a broader range of alternative assumptions is plausible. The range of emissions estimated for the wider set of alternative scenarios is 7 to 14 GtC in 2025 and 5 to 35 GtC in 2100.

- Comparison with other studies of CO_2 scenarios indicates that the IS92a and b fall within the range of other short-term (to 2025) scenarios, including those of the World Energy Council, the International Energy Agency, and the Commission of the European Communities. By the year 2100, the IS92a and b are below but not distant from all the other long-term CO_2 scenarios reported except one. However, the range of alternative, new IS92 Scenarios encompasses virtually all the other scenarios, with a spread of almost an order of magnitude.

- There remains an important need to improve the estimates of greenhouse gas emissions in all sectors (especially in the forest and agriculture sectors) as well as of the underlying human-related variables (such as rates of land clearing).

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INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

CLIMATE CHANGE 1992
The Supplementary Report to the IPCC Scientific Assessment

Report Prepared for IPCC by Working Group I

Edited by J.T.Houghton, B.A.Callander and S.K.Varney
(Meteorological Office, Bracknell, United Kingdom)

WMO UNEP

<u>Valuation of Ecosystems</u>

Q11. On page 8 of your written testimony you state that "Initial estimates of the total value of global ecosystem services suggest they could be in the trillions of dollars annually."

Please document this statement.

A11. Attached is a paper called "The value of the world's ecosystem services and natural capital," by Robert Costanza, et al., which was published in Volume 387 of *Nature* on May 15, 1997. This paper represents an innovative multidisciplinary approach to estimating the value of the services provided by ecological systems. In it, the authors, who are ecologists and economists, estimate the current economic value of 17 ecosystem services for 16 biomes to be in the range of $16-54 trillion per year. Note that the authors state that "Because of the nature of the uncertainties, this must be considered a minimum estimate."

articles

The value of the world's ecosystem services and natural capital

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The services of ecological systems and the natural capital stocks that produce them are critical to the functioning of the Earth's life-support system. They contribute to human welfare, both directly and indirectly, and therefore represent part of the total economic value of the planet. We have estimated the current economic value of 17 ecosystem services for 16 biomes, based on published studies and a few original calculations. For the entire biosphere, the value (most of which is outside the market) is estimated to be in the range of US$16–54 trillion ($10^{12}$) per year, with an average of US$33 trillion per year. Because of the nature of the uncertainties, this must be considered a minimum estimate. Global gross national product total is around US$18 trillion per year.

Because ecosystem services are not fully 'captured' in commercial markets or adequately quantified in terms comparable with economic services and manufactured capital, they are often given too little weight in policy decisions. This neglect may ultimately compromise the sustainability of humans in the biosphere. The economies of the Earth would grind to a halt without the services of ecological life-support systems, so in one sense their total value to the economy is infinite. However, it can be instructive to estimate the 'incremental' or 'marginal' value of ecosystem services (the estimated rate of change of value compared with changes in ecosystem services from their current levels). There have been many studies in the past few decades aimed at estimating the value of a wide variety of ecosystem services. We have gathered together this large (but scattered) amount of information and present it here in a form useful for ecologists, economists, policy makers and the general public. From this synthesis, we have estimated values for ecosystem services per unit area by biome, and then multiplied by the total area of each biome and summed over all services and biomes.

Although we acknowledge that there are many conceptual and empirical problems inherent in producing such an estimate, we think this exercise is essential in order to: (1) make the range of potential values of the services of ecosystems more apparent; (2) establish at least a first approximation of the relative magnitude of global ecosystem services; (3) set up a framework for their further analysis; (4) point out those areas most in need of additional research; and (5) stimulate additional research and debate. Most of the problems and uncertainties we encountered indicate that our estimate represents a minimum value, which would probably increase: (1) with additional effort in studying and valuing a broader range of ecosystem services; (2) with the incorporation of more realistic representations of ecosystem dynamics and interdependence; and (3) as ecosystem services become more stressed and 'scarce' in the future.

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Ecosystem functions and ecosystem services

Ecosystem functions refer variously to the habitat, biological or system properties or processes of ecosystems. Ecosystem goods (such as food) and services (such as waste assimilation) represent the benefits human populations derive, directly or indirectly, from ecosystem functions. For simplicity, we will refer to ecosystem goods and services together as ecosystem services. A large number of functions and services can be identified[1–4]. Reference 5 provides a recent, detailed compendium on describing, measuring and valuing ecosystem services. For the purposes of this analysis we grouped ecosystem services into 17 major categories. These groups are listed in Table 1. We included only renewable ecosystem services, excluding non-renewable fuels and minerals and the atmosphere. Note that ecosystem services and functions do not necessarily show a one-to-one correspondence. In some cases a single ecosystem service is the product of two or more ecosystem functions whereas in other cases a single ecosystem function contributes to two or more ecosystem services. It is also important to emphasize the interdependent nature of many ecosystem functions. For example, some of the net primary production in an ecosystem ends up as food, the consumption of which generates respiratory products necessary for primary production. Even though these functions and services are interdependent, in many cases they can be added because they represent 'joint products' of the ecosystem, which support human welfare. To the extent possible, we have attempted to distinguish joint and 'a 'dable' products from products that would represent 'double counting' (because they represent different aspects of the same service) if they were added. It is also important to recognize that a minimum level of ecosystem 'infrastructure' is necessary in order to allow production of the range of services shown in Table 1. Several authors have stressed the importance of this 'infrastructure' of the ecosystem itself as a contributor to its total value[6,7]. This component of the value is not included in the current analysis.

Natural capital and ecosystem services

In general, capital is considered to be a stock of materials or information that exists at a point in time. Each form of capital stock generates, either autonomously or in conjunction with services from other capital stocks, a flow of services that may be used to transform materials, or the spatial configuration of materials, to enhance the welfare of humans. The human use of this flow of services may or may not leave the original capital stock intact. Capital stock takes different identifiable forms, most notably in physical forms including natural capital, such as trees, minerals, ecosystems, the atmosphere and so on; manufactured capital, such as machines and buildings; and the human capital of physical bodies. In addition, capital stocks can take intangible forms, especially as information such as that stored in computers and in individual human brains, as well as that stored in species and ecosystems.

Ecosystem services consist of flows of materials, energy, and information from natural capital stocks which combine with manufactured and human capital services to produce human welfare. Although it is possible to imagine generating human welfare without natural capital and ecosystem services in artificial 'space colonies', this possibility is too remote and unlikely to be of

Table 1 Ecosystem services and functions used in this study

Number	Ecosystem service*	Ecosystem functions	Examples
1	Gas regulation	Regulation of atmospheric chemical composition	CO_2/O_2 balance, O_3 for UVB protection, and SO_x levels
2	Climate regulation	Regulation of global temperature, precipitation, and other biologically mediated climatic processes at global or local levels	Greenhouse gas regulation, DMS production affecting cloud formation
3	Disturbance regulation	Capacitance, damping and integrity of ecosystem response to environmental fluctuations	Storm protection, flood control, drought recovery and other aspects of habitat response to environmental variability mainly controlled by vegetation structure.
4	Water regulation	Regulation of hydrological flows.	Provisioning of water for agricultural (such as irrigation) or industrial (such as milling) processes or transportation
5	Water supply	Storage and retention of water.	Provisioning of water by watersheds, reservoirs and aquifers.
6	Erosion control and sediment retention	Retention of soil within an ecosystem.	Prevention of loss of soil by wind, runoff, or other removal processes, storage of stilt in lakes and wetlands
7	Soil formation	Soil formation processes	Weathering of rock and the accumulation of organic material.
8	Nutrient cycling	Storage, internal cycling, processing and acquisition of nutrients.	Nitrogen fixation, N, P and other elemental or nutrient cycles.
9	Waste treatment	Recovery of mobile nutrients and removal or breakdown of excess or xenic nutrients and compounds.	Waste treatment, pollution control, detoxification.
10	Pollination	Movement of floral gametes	Provisioning of pollinators for the reproduction of plant populations.
11	Biological control	Trophic-dynamic regulations of populations.	Keystone predator control of prey species, reduction of herbivory by top predators.
12	Refugia	Habitat for resident and transient populations.	Nurseries, habitat for migratory species, regional habitats for locally harvested species, or overwintering grounds.
13	Food production	That portion of gross primary production extractable as food	Production of fish, game, crops, nuts, fruits by hunting, gathering, subsistence farming or fishing
14	Raw materials	That portion of gross primary production extractable as raw materials.	The production of lumber, fuel or fodder
15	Genetic resources	Sources of unique biological materials and products	Medicine, products for materials science, genes for resistance to plant pathogens and crop pests, ornamental species (pets and horticultural varieties of plants).
16	Recreation	Providing opportunities for recreational activities.	Eco-tourism, sport fishing, and other outdoor recreational activities.
17	Cultural	Providing opportunities for non-commercial uses	Aesthetic, artistic, educational, spiritual, and/or scientific values of ecosystems.

* We include ecosystem 'goods' along with ecosystem services

much current interest. In fact, one additional way to think about the value of ecosystem services is to determine what it would cost to replicate them in a technologically produced, artificial biosphere. Experience with manned space missions and with Biosphere II in Arizona indicates that this is an exceedingly complex and expensive proposition. Biosphere I (the Earth) is a very efficient, least-cost provider of human life-support services.

Thus we can consider the general class of natural capital as essential to human welfare. Zero natural capital implies zero human welfare because it is not feasible to substitute, in total, purely 'non-natural' capital for natural capital. Manufactured and human capital require natural capital for their construction[7]. Therefore, it is not very meaningful to ask the total value of natural capital to human welfare, nor to ask the value of massive, particular forms of natural capital. It is trivial to ask what is the value of the atmosphere to humankind, or what is the value of rocks and soil infrastructure as support systems. Their value is infinite in total.

However, it is meaningful to ask how changes in the quantity or quality of various types of natural capital and ecosystem services may have an impact on human welfare. Such changes include both small changes at large scales and large changes at small scales. For example, changing the gaseous composition of the global atmosphere by a small amount may have large-scale climate change effects that will affect the viability and welfare of global human populations. Large changes at small scales include, for example, dramatically changing local forest composition. These changes may dramatically alter terrestrial and aquatic ecosystems, having an impact on the benefits and costs of local human activities. In general, changes in particular forms of natural capital and ecosystem services will alter the costs or benefits of maintaining human welfare.

Valuation of ecosystem services

The issue of valuation is inseparable from the choices and decisions we have to make about ecological systems[6,8]. Some argue that valuation of ecosystems is either impossible or unwise, that we cannot place a value on such 'intangibles' as human life, environmental aesthetics, or long-term ecological benefits. But, in fact, we do so every day. When we set construction standards for highways, bridges and the like, we value human life (acknowledged or not) because spending more money on construction would save lives. Another frequent argument is that we should protect ecosystems for purely moral or aesthetic reasons, and we do not need valuations of ecosystems for this purpose. But there are equally compelling moral arguments that may be in direct conflict with the moral argument to protect ecosystems; for example, the moral argument that no one should go hungry. Moral arguments translate the valuation and decision problem into a different set of dimensions and a different language of discourse[6]; one that, in our view, makes the problem of valuation and choice more difficult and less explicit. But moral and economic arguments are certainly not mutually exclusive. Both discussions can and should go on in parallel.

So, although ecosystem valuation is certainly difficult and fraught with uncertainties, one choice we do not have is whether or not to do it. Rather, the decisions we make as a society about ecosystems imply valuations (although not necessarily expressed in monetary terms). We can choose to make these valuations explicit or not; we can do them with an explicit acknowledgement of the huge uncertainties involved or not; but as long as we are forced to make choices, we are going through the process of valuation.

The exercise of valuing the services of natural capital 'at the margin' consists of determining the differences that relatively small changes in these services make to human welfare. Changes in quality or quantity of ecosystem services have value insofar as they either change the benefits associated with human activities or change the costs of those activities. These changes in benefits and costs either have an impact on human welfare through established markets or through non-market activities. For example, coral reefs provide habitats for fish. One aspect of their value is to increase and concentrate fish stocks. One effect of changes in coral reef quality or quantity would be discernible in commercial fisheries markets, or in recreational fisheries. But other aspects of the value of coral reefs, such as recreational diving and biodiversity conservation, do not show up completely in markets. Forests provide timber materials through well established markets, but the associated habitat values of forests are also felt through unmarketed recreational activities. The chains of effects from ecosystem services to human welfare can range from extremely simple to exceedingly complex. Forests provide timber, but also hold soils and moisture, and create microclimates, all of which contribute to human welfare in complex, and generally non-marketed ways.

Valuation methods

Various methods have been used to estimate both the market and non-market components of the value of ecosystem services[9–16]. In this analysis, we synthesized previous studies based on a wide variety of methods, noting the limitations and assumptions underlying each.

Many of the valuation techniques used in the studies covered in our synthesis are based, either directly or indirectly, on attempts to estimate the 'willingness-to-pay' of individuals for ecosystem services. For example, if ecological services provided a $50 increment to the timber productivity of a forest, then the beneficiaries of this service should be willing to pay up to $50 for it. In addition to timber production, if the forest offered non-marketed, aesthetic, existence, and conservation values of $70, those receiving this non-market benefit should be willing to pay up to $70 for it. The total

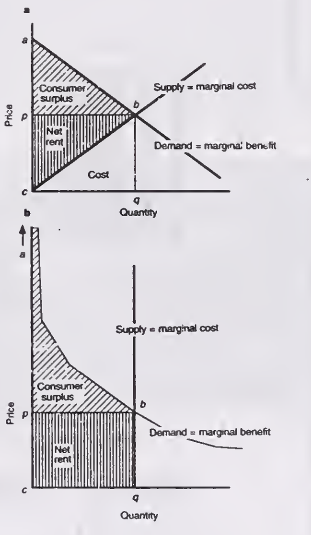

Figure 1 Supply and demand curves, showing the definitions of cost, net rent and consumer surplus for normal goods (**a**) and some essential ecosystem services (**b**). See text for further explanation.

Table 2 Summary of average global value of annual ecosystem services

Biome	Area (ha × 10⁶)	1 Gas regulation	2 Climate regulation	3 Disturbance regulation	4 Water regulation	5 Water supply	6 Erosion control	7 Soil formation	8 Nutrient cycling	9 Waste treatment	10 Pollination	11 Biological control	12 Habitat/refugia	13 Food production	14 Raw materials	15 Genetic resources	16 Recreation	17 Cultural	Total value per ha ($ ha⁻¹ yr⁻¹)	Total global flow value ($ yr⁻¹ × 10⁹)
		Ecosystem services (1994 US$ ha⁻¹ yr⁻¹)																		
Marine	36,302																		577	20,949
Open ocean	33,200	38							118			5		15	0			76	252	8,381
Coastal	3,102			88					3,677			38	8	93	4		82	62	4,052	12,568
Estuaries	180			567					21,100			78	131	521	25		381	29	22,832	4,110
Seagrass/algae beds	200								19,002						2				19,004	3,801
Coral reefs	62			2,750						58		5	7	220	27		3,008	1	6,075	375
Shelf	2,660								1,431			39		68	2			70	1,610	4,283
Terrestrial	15,323																		804	12,319
Forest	4,855		141	2	2	3	96	10	361	87		2		43	138	16	66	2	969	4,706
Tropical	1,900		223	5	6	8	245	10	922	87				32	315	41	112	2	2,007	3,813
Temperate/boreal	2,955		88		0			10		87		4		50	25		36	2	302	894
Grass/rangelands	3,898	7	0		3		29	1		87	25	23		67		0	2		232	906
Wetlands	330	133		4,539	15	3,800				4,177			304	256	106		574	881	14,785	4,879
Tidal marsh/mangroves	165			1,839						6,696			169	466	162		658		9,990	1,648
Swamps/floodplains	165	265		7,240	30	7,600				1,659			439	47	49		491	1,761	19,580	3,231
Lakes/rivers	200				5,445	2,117				665				41			230		8,498	1,700
Desert	1,925																			
Tundra	743																			
Ice/rock	1,640																			
Cropland	1,400										14	24		54					92	128
Urban	332																			
Total	51,625	1,341	684	1,779	1,115	1,692	576	53	17,075	2,277	117	417	124	1,386	721	79	815	3,015		33,268

Numbers in the body of the table are in $ ha⁻¹ yr⁻¹. Row and column totals are in $ yr⁻¹ × 10⁹, column totals are the sum of the products of the per ha services in the table and the area of each biome, not the sum of the per ha services themselves. Shaded cells indicate services that do not occur or are known to be negligible. Open cells indicate lack of available information.

value of ecological services would be \$120, but the contribution to the money economy of ecological services would be \$50, the amount that actually passes through markets. In this study we have tried to estimate the total value of ecological services, regardless of whether they are currently marketed.

Figure 1 shows some of these concepts diagrammatically. Figure 1a shows conventional supply (marginal cost) and demand (marginal benefit) curves for a typical marketed good or service. The value that would show up in gross national product (GNP) is the market price *p* times the quantity *q*, or the area *pbqc*. There are three other relevant areas represented on the diagram, however. The cost of production is the area under the supply curve, *cbq*. The 'producer surplus' or 'net rent' for a resource is the area between the market price and the supply curve, *pbc*. The 'consumer surplus' or the amount of welfare the consumer receives over and above the price paid in the market is the area between the demand curve and the market price, *abp*. The total economic value of the resource is the sum of the producer and consumer surplus (excluding the cost of production), or the area *abc* on the diagram. Note that total economic value can be greater or less than the price times quantity estimates used in GNP.

Figure 1a refers to a human-made, substitutable good. Many ecosystem services are only substitutable up to a point, and their demand curves probably look more like Fig. 1b. Here the demand approaches infinity as the quantity available approaches zero (or some minimum necessary level of services), and the consumer surplus (as well as the total economic value) approaches infinity. Demand curves for ecosystem services are very difficult, if not impossible, to estimate in practice. In addition, to the extent that ecosystem services cannot be increased or decreased by actions of the economic system, their supply curves are more nearly vertical, as shown in Fig. 1b.

In this study we estimated the value per unit area of each ecosystem service for each ecosystem type. To estimate this 'unit value' we used (in order of preference) either: (1) the sum of consumer and producer surplus; or (2) the net rent (or producer surplus); or (3) price times quantity as a proxy for the economic value of the service, assuming that the demand curve for ecosystem services looks more like Fig. 1b than Fig. 1a, and that therefore the area *pbqc* is a conservative underestimate of the area *abc*. We then multiplied the unit values times the surface area of each ecosystem to arrive at global totals.

Ecosystem values, markets and GNP

As we have noted, the value of many types of natural capital and ecosystem services may not be easily traceable through well functioning markets, or may not show up in markets at all. For example, the aesthetic enhancement of a forest may alter recreational expenditures at that site, but this change in expenditure bears no necessary relation to the value of the enhancement. Recreationists may value the improvement at \$100, but transfer only \$20 in spending from other recreational areas to the improved site. Enhanced wetlands quality may improve waste treatment, saving on potential treatment costs. For example, tertiary treatment by wetlands may save \$100 in alternative treatment. Existing treatment may cost only \$30. The treatment cost savings does not show up in any market. There is very little relation between the value of services and observable current spending behaviour in many cases.

There is also no necessary relationship between the valuation of natural capital service flows, even on the margin, and aggregate spending, or GNP, in the economy. This is true even if all capital service flows had an impact on well functioning markets. A large part of the contributions to human welfare by ecosystem services are of a purely public goods nature. They accrue directly to humans without passing through the money economy at all. In many cases people are not even aware of them. Examples include clean air and water, soil formation, climate regulation, waste treatment, aesthetic values and good health, as mentioned above.

Global land use and land cover

In order to estimate the total value of ecosystem services, we needed estimates of the total global extent of the ecosystems themselves. We devised an aggregated classification scheme with 16 primary categories as shown in Table 2 to represent current global land use. The major division is between marine and terrestrial systems. Marine was further subdivided into open ocean and coastal, which itself includes estuaries, seagrass/algae beds, coral reefs, and shelf systems. Terrestrial systems were broken down into two types of forest (tropical and temperate/boreal), grasslands/rangelands, wetlands, lakes/rivers, desert, tundra, ice/rock, cropland, and urban. Primary

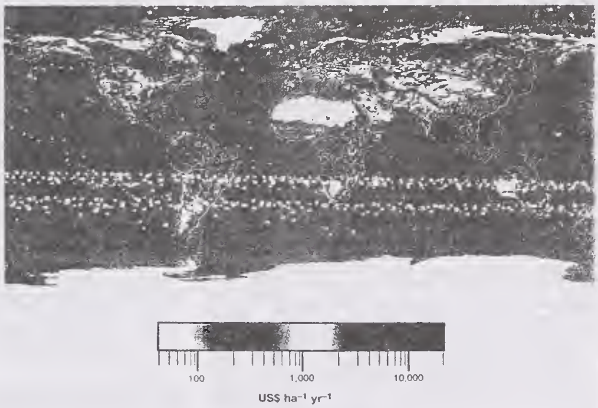

Figure 2 Global map of the value of ecosystem services. See Supplementary Information and Table 2 for details.

data were from ref. 17 as summarized in ref. 4 with additional information from a number of sources[18–22]. We also used data from ref. 23, as a cross-check on the terrestrial estimates and refs 24 and 25 as a check on the marine estimates. The 32 landcover types of ref. 17 were recategorized for Table 2 and Fig. 2. The major assumptions were: (1) chaparral and steppe were considered rangeland and combined with grasslands; and (2) a variety of tropical forest and woodland types were combined into 'tropical forests'.

Synthesis

We conducted a thorough literature review and synthesized the information, along with a few original calculations, during a one-week intensive workshop at the new National Center for Ecological Analysis and Synthesis (NCEAS) at the University of California at Santa Barbara. Supplementary Information lists the primary results for each ecosystem service and biome. Supplementary Information includes all the estimates we could identify from the literature (from over 100 studies), their valuation methods, location and stated value. We converted each estimate into 1994 US$ $ha^{-1} yr^{-1}$ using the USA consumer price index and other conversion factors as needed. These are listed in the notes to the Supplementary Information. For some estimates we also converted the service estimate into US$ equivalents using the ratio of purchasing power GNP per capita for the country of origin to that of the USA. This was intended to adjust for income effects. Where possible the estimates are stated as a range, based on the high and low values found in the literature, and an average value, with annotated comments as to methods and assumptions. We also included in the Supplementary Information some estimates from the literature on 'total ecosystem value', mainly using energy analysis techniques[10]. We did not include these estimates in any of the totals or averages given below, but only for comparison with the totals from the other techniques. Interestingly, these different methods showed fairly close agreement in the final results.

Each biome and each ecosystem service had its special considerations. Detailed notes explaining each biome and each entry in Supplementary Information are given in notes following the table. More detailed descriptions of some of the ecosystems, their services, and general valuation issues can be found in ref. 5. Below we briefly discuss some general considerations that apply across the board.

Sources of error, limitations and caveats

Our attempt to estimate the total current economic value of ecosystem services is limited for a number of reasons, including:

(1) Although we have attempted to include as much as possible, our estimate leaves out many categories of services, which have not yet been adequately studied for many ecosystems. In addition, we could identify no valuation studies for some major biomes (desert, tundra, ice/rock, and cropland). As more and better information becomes available we expect the total estimated value to increase.

(2) Current prices, which form the basis (either directly or indirectly) of many of the valuation estimates, are distorted for a number of reasons, including the fact that they exclude the value of ecosystem services, household labour and the informal economy. In addition to this, there are differences between total value, consumer surplus, net rent (or producer surplus) and $p \times q$, all of which are used to estimate unit values (see Fig. 1).

(3) In many cases the values are based on the current willingness-to-pay of individuals for ecosystem services, even though these individuals may be ill-informed and their preferences may not adequately incorporate social fairness, ecological sustainability and other important goals[16]. In other words, if we actually lived in a world that was ecologically sustainable, socially fair and where everyone had perfect knowledge of their connection to ecosystem services, both market prices and surveys of willingness-to-pay would yield very different results than they currently do, and the value of ecosystem services would probably increase.

(4) In calculating the current value, we generally assumed that the demand and supply curves look something like Fig. 1a. In reality, supply curves for many ecosystem services are more nearly inelastic vertical lines, and the demand curves probably look more like Fig. 1b, approaching infinity as quantity goes to zero. Thus the consumer and producer surplus and thereby the total value of ecosystem services would also approach infinity.

(5) The valuation approach taken here assumes that there are no sharp thresholds, discontinuities or irreversibilities in the ecosystem response functions. This is almost certainly not the case. Therefore this valuation yields an underestimate of the total value.

(6) Extrapolation from point estimates to global totals introduces error. In general, we estimated unit area values for the ecosystem services (in $ $ha^{-1} yr^{-1}$) and then multiplied by the total area of each biome. This can only be considered a crude first approximation and can introduce errors depending on the type of ecosystem service and its spatial heterogeneity.

(7) To avoid double counting, a general equilibrium framework that could directly incorporate the interdependence between ecosystem functions and services would be preferred to the partial equilibrium framework used in this study (see below).

(8) Values for individual ecosystem functions should be based on sustainable use levels, taking account of both the carrying capacity for individual functions (such as food-production or waste recycling) and the combined effect of simultaneous use of more functions. Ecosystems should be able to provide all the functions listed in Table 1 simultaneously and indefinitely. This is certainly not the case for some current ecosystem services because of overuse at existing prices.

(9) We have not incorporated the 'infrastructure' value of ecosystems, as noted above, leading to an underestimation of the total value.

(10) Inter-country comparisons of valuation are affected by income differences. We attempted to address this in some cases using the relative purchasing power GNP per capita of the country relative to the USA, but this is a very crude way to make the correction.

(11) In general, we have used annual flow values and have avoided many of the difficult issues involved with discounting future flow values to arrive at a net present value of the capital stock. But a few estimates in the literature were stated as stock values, and it was necessary to assume a discount rate (we used 5%) in order to convert them into annual flows.

(12) Our estimate is based on a static 'snapshot' of what is, in fact, a complex, dynamic system. We have assumed a static and 'partial equilibrium' model in the sense that the value of each service is derived independently and added. This ignores the complex interdependencies between the services. The estimate could also change drastically as the system moved through critical non-linearities or thresholds. Although it is possible to build 'general equilibrium' models in which the value of all ecosystem services are derived simultaneously with all other values, and to build dynamic models that can incorporate non-linearities and thresholds, these models have rarely been attempted at the scale we are discussing. They represent the next logical step in deriving better estimates of the value of ecosystem services.

We have tried to expose these various sources of uncertainty wherever possible in Supplementary Information and its supporting notes, and state the range of relevant values. In spite of the limitations noted above, we believe it is very useful to synthesize existing valuation estimates, if only to determine a crude, initial magnitude. In general, because of the nature of the limitations noted, we expect our current estimate to represent a minimum value for ecosystem services.

Total global value of ecosystem services

Table 2 is a summary of the results of our synthesis. It lists each of the major biomes along with their current estimated global surface area, the average (on a per hectare basis) of the estimated values of the 17 ecosystem services we have identified from Supplementary Information, and the total value of ecosystem services by biome, by service type and for the entire biosphere.

We estimated that at the current margin, ecosystems provide at least US$33 trillion dollars worth of services annually. The majority of the value of services we could identify is currently outside the market system, in services such as gas regulation (US$1.3 trillion yr^{-1}), disturbance regulation (US$1.8 trillion yr^{-1}), waste treatment (US$2.3 trillion yr^{-1}) and nutrient cycling (US$17 trillion yr^{-1}). About 63% of the estimated value is contributed by marine systems (US$20.9 trillion yr^{-1}). Most of this comes from coastal systems (US$10.6 trillion yr^{-1}). About 38% of the estimated value comes from terrestrial systems, mainly from forests (US$4.7 trillion yr^{-1}) and wetlands (US$4.9 trillion yr^{-1}).

We estimated a range of values whenever possible for each entry in Supplementary Information. Table 2 reports only the average values. Had we used the low end of the range in Supplementary Information, the global total would have been around US$19 trillion. If we eliminate nutrient cycling, which is the largest single service, estimated at US$17 trillion, the total annual value would be around US$16 trillion. Had we used the high end for all estimates, along with estimating the value of desert, tundra and ice/rock as the average value of rangelands, the estimate would be around US$54 trillion. So the total range of annual values we estimated were from US$16–$54 trillion. This is not a huge range, but other sources of uncertainty listed above are much more critical. It is important to emphasize, however, that despite the many uncertainties included in this estimate, it is almost certainly an underestimate for several reasons, as listed above.

There have been very few previous attempts to estimate the total global value of ecosystem services with which to compare these results. We identified two, based on completely different methods and assumptions, both from each other and from the methods used in this study. They thus provide an interesting check.

One was an early attempt at a static general equilibrium input–output model of the globe, including both ecological and economic processes and commodities[26,27]. This model divided the globe in to 9 commodities or product groups and 9 processes, two of which were 'economic' (urban and agriculture) and 7 of which were 'ecological', including both terrestrial and marine systems. Data were from about 1970. Although this was a very aggregated breakdown and the data was of only moderate quality, the model produced a set of 'shadow prices' and 'shadow values' for all the flows between processes, as well as the net outputs from the system, which could be used to derive an estimate of the total value of ecosystem services. The input–output format is far superior to the partial equilibrium format we used in this study for differentiating gross from net flows and avoiding double counting. The results yielded a total value of the net output of the 7 global ecosystem processes equal to the equivalent of US$9.4 trillion in 1972. Converted to 1994 US$ this is about $34 trillion, surprisingly close to our current average estimate. This estimate broke down into US$11.9 trillion (or 35%) from terrestrial ecosystem processes and US$22.1 trillion (or 65%) from marine processes, also very close to our current estimate. World GNP in 1970 was about $14.3 trillion (in 1994 US$), indicating a ratio of total ecosystem services to GNP of about 2.4 to 1. The current estimate has a corresponding ratio of 1.8 to 1.

A more recent study[28] estimated a 'maximum sustainable surplus' value of ecosystem services by considering ecosystem services as one input to an aggregate global production function along with labour and manufactured capital. Their estimates ranged from US$3.4 to US$17.6 trillion yr^{-1}, depending on various assumptions. This approach assumed that the total value of ecosystem services is limited to that which has an impact on marketed value, either directly or indirectly, and thus cannot exceed the total world GNP of about US$18 trillion. But, as we have pointed out, only a fraction of ecosystem services affects private goods traded in existing markets, which would be included in measures such as GNP. This is a subset of the services we estimated, so we would expect this estimate to undervalue total ecosystem services.

The results of both of these studies indicate, however, that our current estimate is at least in approximately the same range. As we have noted, there are many limitations to both the current and these two previous studies. They are all only static snapshots of a biosphere that is a complex, dynamic system. The obvious next steps include building regional and global models of the linked ecological economic system aimed at a better understanding of both the complex dynamics of physical/biological processes and the value of these processes to human well-being[29,30]. But we do not have to wait for the results of these models to draw the following conclusions.

Discussion

What this study makes abundantly clear is that ecosystem services provide an important portion of the total contribution to human welfare on this planet. We must begin to give the natural capital stock that produces these services adequate weight in the decision-making process, otherwise current and continued future human welfare may drastically suffer. We estimate in this study that the annual value of these services is US$16–54 trillion, with an estimated average of US$33 trillion. The real value is almost certainly much larger, even at the current margin. US$33 trillion is 1.8 times the current global GNP. One way to look at this comparison is that if one were to try to replace the services of ecosystems at the current margin, one would need to increase global GNP by at least US$33 trillion, partly to cover services already captured in existing GNP and partly to cover services that are not currently captured in GNP. This impossible task would lead to no increase in welfare because we would only be replacing existing services, and it ignores the fact that many ecosystem services are literally irreplaceable.

If ecosystem services were actually paid for, in terms of their value contribution to the global economy, the global price system would be very different from what it is today. The price of commodities using ecosystem services directly or indirectly would be much greater. The structure of factor payments, including wages, interest rates and profits would change dramatically. World GNP would be very different in both magnitude and composition if it adequately incorporated the value of ecosystem services. One practical use of the estimates we have developed is to help modify systems of national accounting to better reflect the value of ecosystem services and natural capital. Initial attempts to do this paint a very different picture of our current level of economic welfare than conventional GNP, some indicating a levelling of welfare since about 1970 while GNP has continued to increase[31–33]. A second important use of these estimates is for project appraisal, where ecosystem services lost must be weighed against the benefits of a specific project[8]. Because ecosystem services are largely outside the market and uncertain, they are too often ignored or undervalued, leading to the error of constructing projects whose social costs far outweight their benefits.

As natural capital and ecosystem services become more stressed and more 'scarce' in the future, we can only expect their value to increase. If significant, irreversible thresholds are passed for irreplaceable ecosystem services, their value may quickly jump to infinity. Given the huge uncertainties involved, we may never have a very precise estimate of the value of ecosystem services. Nevertheless, even the crude initial estimate we have been able to assemble is a useful starting point (we stress again that it is only a starting point). It demonstrates the need for much additional research and it also indicates the specific areas that are most in need of additional study. It also highlights the relative importance of ecosystem services and the potential impact on our welfare of continuing to squander them. □

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Supplementary Information is on www nature com Paper copies are avaialble from Mary Sheehan at the London editorial office of *Nature*.

<u>**Objective of the United Nations Framework Convention on Climate Change**</u>

Q12. As you note on page 8 of your testimony, the Article 2 of the United Nations Framework Convention on Climate Change states that "The ultimate objective of this Convention . . . is to achieve . . . stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system."

Q12.1 How is this level to be determined?

A12.1. There is no prescribed method for determining the stabilization level of greenhouse gas concentrations that would avoid dangerous "anthropogenic interference with the climate system." However, it is clear that research and scientific information must inform our efforts to establish a stabilization target, but they alone cannot determine what levels would be "dangerous." Your question does not cite several additional points in Article 2, which state that stabilization should be achieved within a timeframe that allows ecosystems to adapt naturally to climate change and ensures that food production is not threatened. Both points emphasize the importance of the <u>rate of change,</u> as well as the ultimate concentration of greenhouse gases. If temperature changes too quickly, we may lose the ability to cope or adapt. Concerns about rate of change make early action more important. Subjective judgments must also be made by society regarding what attributes of the current climate are most important to preserve, and what levels of risk society is willing to take. These collective value judgments must be reached in our country through open political debate and discussion.

Once these attributes have been identified, scientific information must play a critical role by objectively describing the ways in which different concentrations of greenhouse gases, and hence different rates and magnitudes of climate change, would affect the values that have been collectively agreed are important to protect. To some degree, science can describe and quantify the ways in which many environmental systems (e.g., forests, grasslands, mountain ecosystems, and wetlands) and socioeconomic sectors (e.g., agriculture, water resources, insurance/ financial services, and human health) will be affected when exposed to different rates and magnitudes of climate change. Perhaps we can also identify thresholds of climate change, which if exceeded, would disrupt environmental systems and render them unable to provide needed environmental goods and services. This scientific information is critical to determining whether the climate change associated with different stabilization levels would protect or disrupt valued environmental systems.

Given the long time scales involved in reversing damage -- decades to centuries -- the Framework Convention on Climate Change (FCCC) clearly and, in my view, appropriately, notes that taking precautions is important, because some of the consequences we face are irreversible. Article 3 of the FCCC states that:

"The Parties should take precautionary measures to anticipate, prevent or minimize the causes of climate change and mitigate its adverse effects. Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing such measures, taking into account that policies and measures to deal with climate change should be cost-effective so as to ensure global benefits at the lowest possible cost."

Different countries clearly have identified different stabilization levels, which, according to their own criteria, meet the objectives of the FCCC. This leads to the need for international negotiations to establish agreement on a common greenhouse gas level that should not be exceeded. Clearly, such international negotiation is a political process, and its outcome cannot be determined through a scientific research, although again, scientific research and information are a critical component of the process.

Q12.2 What is the scientific justification for setting greenhouse-gas stabilization at this level?

A12.2 As stated above, research and scientific information are a central component of the process of determining what the appropriate stabilization level should be. We have not yet determined a long-term stabilization target. We will take the precautions described in the FCCC into account when considering such a target.

Q12.3 How is the phrase "dangerous anthropogenic interference with the climate system" defined?

A12.3 There is no internationally agreed definition of "dangerous anthropogenic interference with the climate system." The FCCC does not itself define "dangerous anthropogenic interference," nor does it specify a level of greenhouse gas concentrations that would avoid such interference. The FCCC does spell out a timeframe in which an acceptable level should be reached. The objective of the FCCC (Article 2) states that "Such a level should be achieved within a timeframe sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner."

Q12.4 Will any of the emission reduction proposals currently under consideration achieve this goal of stabilization?

A12.4 The emissions reduction targets in the Kyoto Protocol will not, alone, achieve the goal of stabilization of the atmosphere, but the Kyoto Protocol constitutes an important first step in the process of beginning to reduce the growth in emissions by signaling to decision-makers in the private and public sectors the need to increase energy efficiency and shift to low carbon energy forms. Without these early steps, eventual reductions may be both more difficult and expensive to attain, as enterprises will continue to invest in inefficient capital equipment that will then need to be retired prematurely to meet future emissions reductions targets. Indeed, with unrestrained growth in emissions over the next decades, it will be impossible to reach low stabilization targets in the future, should these be determined to be necessary. And, of course, meeting a low stabilization target will require the meaningful participation of developing countries.

Impacts on Global Agricultural Activity

Q13. On page 9 of your written testimony you state that "a series of projections that includes carbon dioxide increases, temperature change, and precipitation changes now indicate that while there might be no "net" effect on global agricultural productivity, significant regional dislocations are expected, with the poorest countries experiencing the greatest losses."

Please document this statement.

A13. In a 1995 document entitled *As Climate Changes: International Impacts and Implications*, Cynthia Rosenzweig, Martin Parry, and Gunther Fisher reported on a study by 18 agricultural scientists that estimated the potential change in crop yield under three different climate change scenarios. The crops modeled were wheat, rice, and maize, which together account for 85 percent of world cereal exports, and soybean, which accounts for about 67 percent of world trade in protein cake equivalent. The key findings of this study were that:

- "Assuming a minor level of farm-level adaptation (e.g., minor shifts in planting dates and minor changes in crop variety), the net effect of climate change would be to reduce global cereal production by up to 5 percent. This modest reduction could be largely overcome by more major forms of adaptation, such as the installation of irrigation.
- Climate change would increase the disparities between developed and developing countries. Production in the developed world may well benefit from climate change, whereas production in developing nations may decline. Adaptation at the farm level would do little to reduce the disparities, with the developing world suffering the losses.

- Cereal prices and thus the population at risk of hunger in developing countries could increase despite adaptation. Even a high level of farmer adaptation in the agricultural sector would not entirely prevent such adverse effects."

A copy of the chapter (Chapter 2) in which these study results were reported is attached.

In addition, Chapter 13 of the IPCC document *Climate Change 1995 – Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses* reports that crop yield and productivity changes will vary considerably across regions. Lower latitude and lower income countries will be more negatively affected. Low income populations depending on isolated agricultural systems, particularly dryland systems in semi-arid and arid regions, are particularly vulnerable to hunger and severe hardship. A copy of this chapter of the document is attached.

2 World Food Supply

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SUMMARY

Global assessment

THE ESTIMATION OF POTENTIAL CHANGE IN CROP YIELD

Agricultural scientists in 18 countries estimated potential changes in national grain crop yields using compatible crop models and consistent climate change scenarios. The crops modeled were wheat, rice, maize, and soybean. Wheat, rice, and maize account for approximately 85 percent of world cereal exports; soybean accounts for about 67 percent of world trade in protein cake equivalent. The direct effects of carbon dioxide level on crop yields were taken into account. Site-specific estimates of yield changes were aggregated to national levels for the modeled crops. These national crop yield changes were then extrapolated to provide yield change estimates for other countries and other crops.

THE ESTIMATION OF WORLD FOOD TRADE RESPONSES

The national grain crop yield estimates from the climate change scenarios were used as inputs for a world food trade model, the Basic Linked System (BLS). Outputs from simulations by the BLS provided estimates of changes in cereal production, food prices, and the number of people at risk of hunger. The assessment of the implications of climate change on world food supply took the following into account:

The uncertainty about the level of climate change expected
The effects of three climate change scenarios were tested using climate conditions predicted for doubled levels of atmospheric carbon dioxide by three general circulation models: the Goddard Institute for Space Studies (GISS), the Geophysical Fluid Dynamics Laboratory (GFDL), and the UK Meteorological Office (UKMO) models (see Box 2 for analysis of a scenario with lesser warming).

Different adaptive responses
Two levels of farmer adaptation were considered, based on different assumptions about shifts in crop planting dates, changes in crop variety, level of irrigation, and fertilizer application.

The uncertainty about future trade policy and levels of economic and population growth
Alternative pathways of development including partial and full trade liberalization, low and moderate economic growth, and low and medium population growth were considered in the presence and absence of climate change.

Key findings of global assessment

CLIMATE CHANGE WITH CONTINUATION OF CURRENT TRENDS

When the three projections of climate change were imposed on the world food system up to the year 2060, given a continuation of current trends in economic growth rates, partial trade liberalization, and medium population growth rates, it was estimated that:

- Assuming a minor level of farm-level adaptation (e.g., minor shifts in planting dates and minor changes in crop variety), the net effect of climate change would be to reduce global cereal production by up to 5 percent. This modest global reduction could be largely overcome by more major forms of adaptation, such as the installation of irrigation.
- Climate change would increase the disparities in cereal production between developed and developing countries.

Production in the developed world may well benefit from climate change, whereas production in developing nations may decline. Adaptation at the farm level would do little to reduce the disparities, with the developing world suffering the losses.

- Cereal prices and thus the population at risk of hunger in developing countries could increase despite adaptation. Even a high level of farmer adaptation in the agricultural sector would not entirely prevent such adverse effects.

CLIMATE CHANGE WITH ALTERNATIVE ASSUMPTIONS

When alternative assumptions – lowering of trade barriers, low economic growth, and low population growth – were tested in the absence and the presence of climate change, the following projections were made.

In the absence of climate change:

- Full trade liberalization and low population growth would have a beneficial effect in reducing the population at risk of hunger, as compared to the reference case (partial trade liberalization and medium population growth), whereas low economic growth would increase the number of people at risk of hunger.
- The greatest benefits would accrue from following a low population growth pathway into the future.

In the presence of climate change:

- The beneficial effects of full trade liberalization and low population growth would be equal to or (in the case of population, significantly) greater than the adverse effects of climate change. Therefore, there may be much to be gained from altering the conditions of trade and development as a strategy for addressing the climate change issue.
- Cereal production would decrease, particularly in the developing world, while prices and population at risk of hunger would increase due to climate change. The alternate assumptions of trade liberalization, economic development, and population growth made little difference with respect to the geopolitical patterns of relative effects of climate change.
- The magnitude of adverse climate impacts would be the least, however, under the conditions of low population growth. Low population growth would minimize the population at risk of hunger both in the presence and absence of climate change.

Overall, the study suggests that the worst situation would arise from a scenario of severe climate change, low economic growth, and little farm-level adaptation. In order to minimize possible adverse consequences – production losses, food price increases, and people at risk of hunger – the way forward is to encourage the agricultural sector to continue to develop crop breeding and management programs for heat and drought conditions (which would be useful even today in improving productivity in marginal environments), and for the nations of the world to take measures to slow the growth of the human population. The latter step would also be consistent with efforts to slow emissions of greenhouse gases, the source of the problem, and thus the rate and eventual magnitude of global climate change.

INTRODUCTION

In the coming decades, global agriculture faces the prospect of a changing climate (IPCC, 1990a, 1992), as well as the known challenge of feeding a world population that is projected to double its present level of 5 billion by about the year 2060 (International Bank for Reconstruction and Development/World Bank, 1990). The prospective climate change is global warming (with associated changes in hydrological regimes and other climatic variables) induced by the increasing concentration of radiatively active greenhouse gases (IPCC, 1990a, 1992). Climate change could have far-reaching effects on patterns of trade among nations, development, and food security. To help prepare for this uncertain but challenging future, this study examined the potential effects of climate change on crop yields, world food supply, and regions vulnerable to food deficits (see Box 1).

Despite such technological advances as improved crop varieties and irrigation systems, weather and climate are still key factors in agricultural productivity. For example, weak monsoon rains in 1987 caused large shortfalls in crop production in India, Bangladesh, and Pakistan, contributing to reversion to wheat importation by India and Pakistan (World Food Institute, 1988). The 1980s also saw the continuing deterioration of food production in Africa, caused in part by persistent drought and low production potential, and international relief efforts to prevent widespread famine. Moreover, the effects of climate on agriculture in individual countries cannot be considered in isolation. Agricultural trade has grown dramatically in recent decades and now provides significant increments of national food supplies to major importing nations and substantial income for major exporting nations (Table 1). These examples emphasize the close links between agriculture and climate, the international nature of food trade and food security, and the need to consider the impacts of climate change in a global context.

Recent research has focused on regional and national assessments of the potential effects of climate change on agriculture. These efforts have, for the most part, treated each region or nation in isolation, without considering the effects of changes in production in other places. At the same time, there has been a growing emphasis on understanding the interactions of climatic, environmental, and social factors in a wider context (Parry, 1990), leading to more integrated assessments in national agricultural impact

BOX 1. UNDERSTANDING VULNERABILITY TO HUNGER: HOW GREAT IS THE THREAT OF CLIMATE CHANGE?

Vulnerability to hunger is the prospect that the hierarchy of systems that provide an individual with enough food to meet his/her requirements for an active and healthy life may fail. In contrast to the immense driving forces of global change – population change, economic growth, trade liberalization, democratization – hunger is intimately connected with the local nuances of human ecology, exchange entitlement and political economy. The threat of climate change to individual vulnerability depends on household characteristics (for example, too little labor for both timely planting and off-farm employment), socio-economic class (for example, access to wealth), regional production systems (with varying sensitivity to climatic perturbations), and national activities (for example, that acquire and allocate food aid).

While global trends in nutrition and production are well-documented, information on vulnerability is less systematic. Projections into the future are equally uncertain, often depending on critical assumptions, such as the desired metabolic rate, distribution of income, or nature of governance (and the absence of civil strife). Given the local scale of hunger, the difficulty of compiling systematic databases for future projections, and the great potential for surprise in both natural and social systems, a useful approach is to look at climate change as a future risk to present vulnerability. This focus naturally complements research based on scenarios and projections of food systems using integrated or linked models. Research in progress in Zimbabwe aims to define the present and future social space of vulnerability.

Surveys of food security in Zimbabwe delineate livelihood groups that are presently vulnerable to food insecurity – urban (unemployed, informal workers) and rural (communal farmers, landless/farm workers/unemployed) (Table A-1). While the definition of vulnerable groups is robust and widely accepted, reference points for enumerating the extent of vulnerability, food insecurity, poverty, and malnutrition differ in time, region, and measurement. However, a reasonable estimate of the nature and extent of vulnerability in Zimbabwe emerges.

Some 6 percent of the total population are vulnerable to food insecurity in urban areas, comprised of the unemployed and households headed by informal workers. Among these 125,000 households, some 10 percent are headed by divorced, separated, or widowed women – a particularly vulnerable group with low employment, restricted social relations, and high numbers of dependents.

Most of the vulnerable are in rural areas. Agricultural land use in Zimbabwe spans a range from the productive specialized, intensive farming regions of central to eastern Zimbabwe (zones I and II), to the lowland, extensive farming zones of western and southern Zimbabwe (zones IV and V). Communal farmers are smallholder agriculturists, concentrated in the semi-arid, extensive farming zones. Even in years of average production, food-insecure communal farmers number almost 10 percent of the population. Rural households with no land, those dependent on agricultural labor or those with no employment, comprise 12.5 percent of the population. As in urban areas, female-headed households, 3.5 percent of the population, may be critically vulnerable.

Although food security is a priority for national policy, the causes of vulnerability are embedded in the human ecology, political economy, and entitlements relations of post-independence Zimbabwe. Maize, the staple food, has increased in production, more than doubling among communal farmers between the 1970s and 1980s. Yet, only 10–20 percent of communal farmers consistently produce a surplus. Weak macroeconomic performance, inequitable land distribution,

Table A-1. *Vulnerable Livelihood Groups in Zimbabwe, 1991*

Group	Number of Food-Insecure Households[a]	Percent of Population
Urban		
Unemployed	72,000	3.7
Informal Workers	53,000	2.7
Urban Total	125,000	6.4
Rural		
Communal Farmers:[b]		
Zones I and II	20,000–39,000	1–2
Zone III	22,500–98,000	1–5
Zones IV and V	137,000–450,500	7–23
Landless, Farm Workers and Unemployed	210,000	12.5
Rural Total[b]	389,500–797,500	21.5–42.5
Total[b]	514,500–922,500	27.9–48.9

Notes:

[a] Christensen and Sack report estimates of food insecurity based on the confluence of poverty, malnourishment, and variable incomes. This corresponds to our broader definition of vulnerability.

[b] The lower number is food security in years with average rainfall, while the higher number includes additional vulnerability due to exposure to crop failure in years with lower than average rainfall.

Source:

Christensen, G., and J. Stack. 1992. *The Dimensions of Household Food Insecurity in Zimbabwe, 1980–1991.* Working Paper No. 5. Oxford: Food Studies Group.

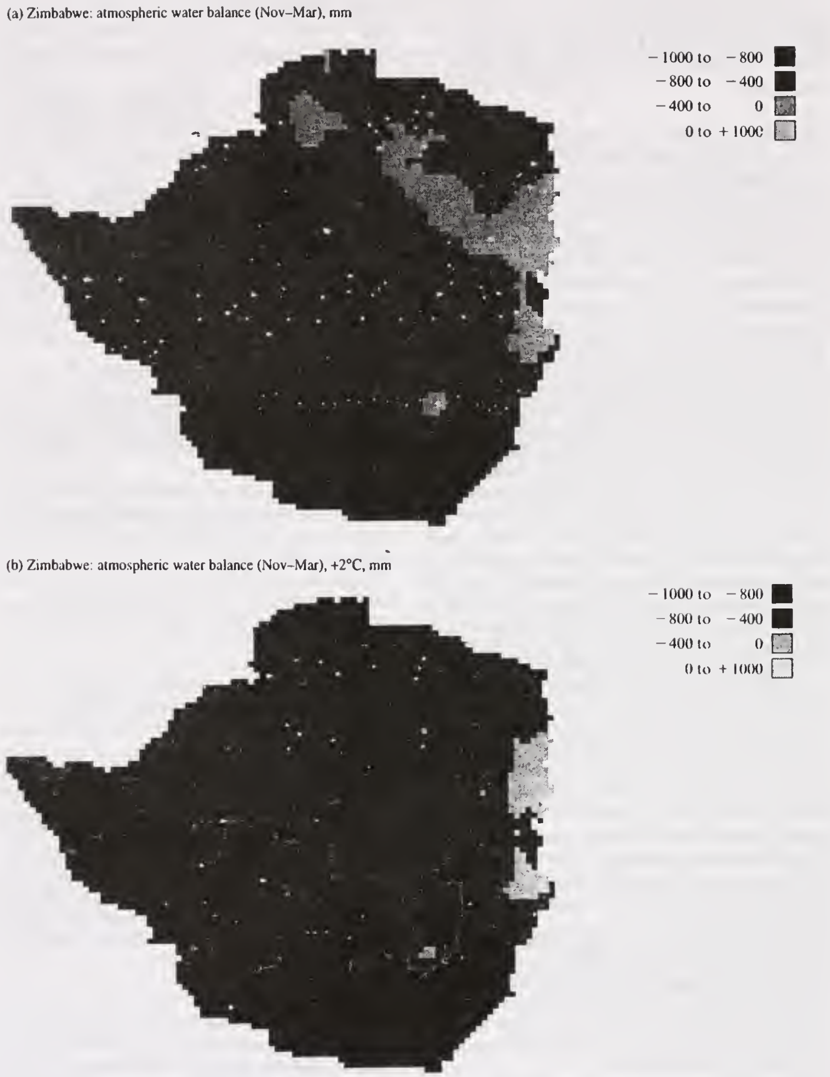

Figure A-1 Seasonal atmospheric water balance in Zimbabwe, precipitation potential evaporation (a) Current average conditions for November to March, and (b) with + 2°C warming. Source: Downing, 1992.

and misdirected social policy all contribute to vulnerability. External shocks of recurrent drought in the last ten years have further stressed vulnerable groups.

Among rural households, vulnerability doubles in times of drought, particularly if national institutions fail to provide timely support. Drought is recurrent in Zimbabwe, with serious impacts in 1991/92. Small changes in agroclimatic resources entail significant spatial shifts of land-use zones.

A simple index of the atmospheric water balance, precipitation minus potential evaporation, gauges the extent to which agricultural land use may be subject to changes in water resources – often the limiting factor in semi-arid regions of Zimbabwe. The present balance shows the wetter highlands (with surplus water) and the extreme water deficits of southern Zimbabwe (Figure A-1a). With a temperature increase of 2°C and no change in precipitation, the wet zones (with a water surplus) decrease by a third, from 9 percent of Zimbabwe to about 2.5 percent (Figure A-1b). The driest two zones double in area. A further increase in temperature, to +4°C, reduces the summer water-surplus zones to less than 2 percent of Zimbabwe, approximately corresponding to the 1991/92 drought.

In addition to a shrinkage of the agricultural area, crop yields in marginal zones would suffer. Simulations for one semi-arid area indicate that with 2°C warming, adequate yields currently expected 70 percent of the time would only be exceeded in less than 40 percent of the years.

Increased risk in food production directly affects vulnerable farmers. Surveys in Buhera, in the semi-extensive, semi-arid farming region near Chisumbanje show that household food security is affected by erratic rainfall, sandy and infertile soils, and low levels of crop technology. Maize yields are low – averaging 650 kg/ha. Farm sizes are relatively large, but households are also large with 10 people on average. Farmers on average fail to support their households. With climate change, household food security would deteriorate, possibly with a 10–20 percent decrease in food availability in vulnerable households.

The semi-extensive farming zone, on the margin of more intensive land uses, appears to be particularly sensitive to small changes in climate. Socioeconomic groups in this area, already vulnerable in terms of self-sufficiency and food security, would be further marginalized. Increased variations in rainfall and yields would alter the mix of appropriate response strategies. Successful farming systems would have to be responsive to both good and bad seasons, implying improved use of weather information, flexible markets for inputs and produce, and reliable drought responses.

Climate change threatens each vulnerable group through the multiple effects that diminish resource endowment, and will possibly increase resource conflicts and tension between agricultural and industrial/commercial sectors. Thus, broad-scale shifts in agricultural capability would affect not only rural populations, but the nation as a whole.

See the following for detailed references:

Downing, T. E. 1992. Climate change and vulnerable places: Global food security and country studies in Zimbabwe, Kenya, Senegal and Chile. Research Report #1. Oxford University, Environmental Change Unit. Oxford: Oxford University.

Bohle, H. G., T. E. Downing, and M. Watts. 1994. Climate change and social vulnerability: toward a sociology and geography of food insecurity. *Global Environmental Change* 4(1).

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studies conducted in the United States (Adams *et al.*, 1990; Smith and Tirpak, 1989), Canada (Smit, 1989), Brazil (Magalhaes, 1992) and Indonesia, Malaysia, and Thailand (Parry *et al.*, 1992). Regional studies have been conducted in high-latitude and semi-arid agricultural areas (Parry *et al.*, 1988a, 1988b) and in the U.S. Midwest (Rosenberg and Crosson, 1991). The results of these and other agricultural impact studies have been summarized in the IPCC Working Group II Report (IPCC, 1990b). Studies of the sensitivity of world agriculture to potential climate changes have indicated that the effect of moderate climate change on world and domestic economies may be small as reduced production in some areas would be balanced by gains in others (Kane *et al.*, 1992). Potential changes in crop yield and distribution have been modeled (Leemans and Solomon, 1993). However, there has, to date, been no integrated (i.e., combined biophysical and economic) assessment of the potential effects of climate change on world agriculture.

The study reported here assessed the potential effects of climate change on world food supply. The research involved estimating the responses of crop yields to greenhouse gas-induced climate change scenarios and then simulating the economic consequences of these potential changes in crop yields. The analysis provides estimates of changes in terms of production and prices of major food crops and the number of people at risk of hunger.

APPROACH

World food supply study design

The structure and research methods for the world food

Table 1. *Major cereal importers and exporters*

A. Major net cereal importers, 1988 (mmt)		B. Major net cereal exporters, 1988 (mmt)	
USSR	34	USA	98
Japan	28	France	27
China	17	Canada	23
Korea, Rep.	9	Australia	15
Egypt	8	Argentina	10
Mexico	6	Thailand	6
Iran	5	Denmark	2
Italy	5	UK	1
Iraq	4	South Africa	1
Saudi Arabia	3	New Zealand	—

Source: FAO, 1988.

supply study are illustrated in Figure 1. There were two main components:

Estimation of potential changes in crop yield

Agricultural scientists in eighteen countries (see Appendices 1 and 2) simulated potential changes in grain yields using compatible crop models developed by the U.S. Agency for International Development's International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT, 1989). The crops modeled were wheat, rice, maize, and soybeans. Wheat, rice, and maize account for approximately 85 percent of world cereal exports; soybean accounts for about 67 percent of world trade in protein cake equivalent. The crop models were run for current climate conditions, for arbitrary changes in climate (2°C and 4°C increases in temperature and +/−20 percent precipitation), and for climate conditions predicted by general circulation models (GCMs) for doubled atmospheric CO_2 levels. The direct effects of increasing levels of CO_2 on crop growth and water use were taken into account. For the GCM climate change scenarios, site-specific estimates of crop yield changes were aggregated by current regional production to estimate national crop yield changes at two levels of farmer adaptation. The national crop yield changes were then extrapolated to provide estimates of yield changes (for the three GCM scenarios) for other countries and crops included in the food trade analysis.

Estimation of world food trade responses

The national crop yield changes derived from the first component of the study were used as inputs for a world food trade model, the Basic Linked System (BLS), developed at the International Institute for Applied Systems Analysis (IIASA) (Fischer *et al.*, 1988). The BLS was run first for a reference scenario projecting the agricultural system to the year 2060 assuming no change in climate, and then with the three GCM climate change scenarios. Other BLS simulations included the effects of two levels of farmer adaptation and scenarios of different future trade liberalization policies and different economic and population growth rates. Outputs from the BLS simulations provided information on food production, food prices, and the number of people at risk of hunger (defined as those with an income insufficient to either produce or procure their food requirements) for these scenarios projected up to the year 2060.

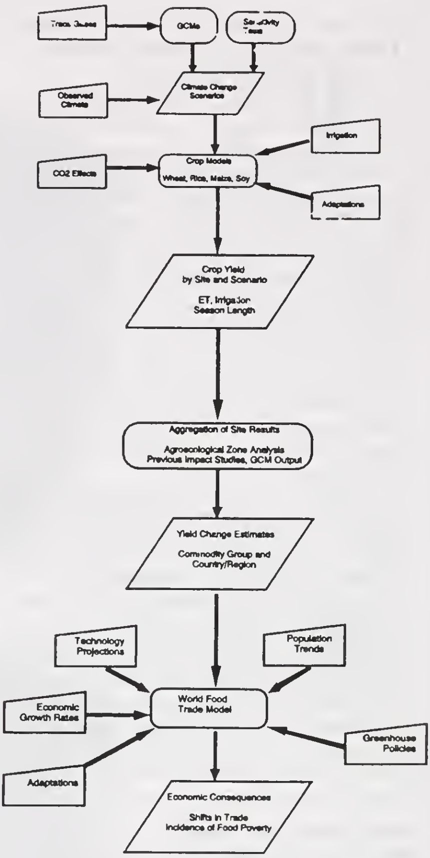

Figure 1 Key elements of the crop yield and world food trade supply

Throughout the climate change study, a distinction was made between *farm-level adaptations*, which were tested by the crop models and result in yield changes, and *economic adjustments* to the yield changes, which were tested by the BLS world food trade model and result in national and regional production changes and price responses. Farm-level adaptations tested in the crop models included shifts in planting date, more climatically adapted crop varieties, changes in amounts of irrigation, and changes in fertilizer application. Economic adjustments tested by the BLS included increased agricultural investment, reallocation of agricultural resources according to economic returns (including crop switching), and reclamation of additional arable land as a response to higher cereal prices. These economic adjustments were assumed not to feed back to the yield levels predicted by the crop modeling study. The crop yield and economic modeling components are described in greater detail below.

Table 2. *GCM climate change scenarios*

				Change in average global	
GCM	Year[1]	Resolution (lat × long)	CO_2 (ppm)	Temperature (°C)	Precipitation (%)
GISS[2]	1982	7.83° × 10°	630	4.2	11
GFDL[3]	1988	4.4° × 7.5°	600	4.0	8
UKMO[4]	1986	5.0° × 7.5°	640	5.2	15

Notes:
[1] When calculated.
[2] Hansen *et al.*, 1983.
[3] Manabe and Wetherald, 1987.
[4] Wilson and Mitchell, 1987.

Climate change scenarios

Sensitivity tests

Arbitrary climate sensitivity tests were conducted to test crop model responses to a range of temperature (+2°C and +4°C) and precipitation (+/−20 percent) changes. The sensitivity test results were not utilized in the economic analysis with the BLS world food trade model because of their lack of realism; for example, temperature change at high latitudes is predicted to be greater than the global mean in winter (IPCC, 1990a) rather than to increase by 2°C or 4°C in all regions of the world throughout the year. Farm-level adaptations were not tested in the sensitivity studies.

Scenarios based on general circulation model results

Scenarios of climate change were developed in order to estimate their effects on crop yields and food trade. The GCMs used were those from the Goddard Institute for Space Studies (GISS), the Geophysical Fluid Dynamics Laboratory (GFDL), and the United Kingdom Meteorological Office (UKMO). (See Chapter 1.) The predictions of these scenarios are presented in Table 2. See Box 2 for analysis of a scenario with lesser warming. Mean monthly changes in temperature, precipitation, and solar radiation from the appropriate GCM grid boxes were applied to observed daily climate records to create climate change scenarios for each site.

CO_2 level and timing

For the crop modeling part of this study, climate changes derived from the doubled CO_2 GCM simulations were utilized with an associated level of 555 ppm CO_2 (see Chapter 1). The 555 ppm CO_2 level is based on the GISS GCM trace gas scenario A (Hansen *et al.*, 1988), in which the simulated climate had warmed to the effective doubled CO_2 level of ~4°C by 2060. The level of CO_2 is important when estimating potential impacts on crops, because crop growth and water use have been shown to benefit from increased levels of CO_2 (Cure and Acock, 1986). For the BLS world food trade projections it was assumed that these conditions would occur in 2060. However, it is not known what the rates of future emissions of trace gases will be and when the full magnitude of their effects will be realized.

Crop models and yield simulations

Crop models

The IBSNAT crop models were utilized by the participating agricultural scientists to estimate how climate change and increasing levels of carbon dioxide may alter yields of world crops at 112 sites in 18 countries. The sites represented both major and minor production areas at low, mid, and high latitudes (Figure 2). The crop models used were CERES-Wheat (Ritchie and Otter, 1985; Godwin *et al.*, 1989), CERES-Maize (Jones and Kiniry, 1986; Ritchie *et al.*, 1989), CERES-Rice (paddy and upland) (Godwin *et al.*, 1993), and SOYGRO (Jones *et al.*, 1989).

The IBSNAT models are composed of parameterizations of important physiological processes responsible for plant growth and development, evapotranspiration, and partitioning of photosynthate to produce economic yield. The simplified functions enable the prediction of the growth of crops as influenced by the major factors that affect yields, i.e., genetics, climate (daily solar radiation, maximum and minimum temperatures, and precipitation), soils, and management practices. This type of dynamic process crop growth model is considered to be a significant advance over traditional regression-based methods (see, e.g., Thompson, 1969) that were used to estimate crop yields from simple climate and management inputs with geographic and temporal specificity. The IBSNAT models include a soil moisture balance submodel so that they could be used to predict both rainfed

BOX 2. ANALYSIS OF GISS-A[1] CLIMATE CHANGE SCENARIO

In order to test a climate scenario with lower levels of projected warming, a fourth climate change scenario was included utilizing modified project methodology. The IBSNAT crop models were run at 70 sites with the climate predicted by the Transient Run A of the GISS GCM for the decade of the 2030s. Wheat, maize, soybean, and rice were simulated at 58, 31, 18, and 8 sites, respectively. Simulations were done with and without physiological CO_2 effects (555 ppm), but farm-level adaptations were not tested. Crop model results by site were then aggregated and extended to create estimates of country yield changes as described in the main body of the chapter and BLS simulations were made with these GISS-A yield change estimates.

As expected, crop yields were less negatively affected by the GISS-A climate change scenario (Figure B-1, Plate 4). However, crop modeling results showed that mean national crop yield changes were still mostly negative without the direct physiological effects of CO_2 on crop growth and yield. Yield changes without direct CO_2 effects ranged from −30 to +20 percent. With direct CO_2 effects, yield changes were mostly positive, ranging from −10 percent to +30 percent. In this case, the beneficial CO_2 effects more than compensated for detrimental climate effects in most locations. The geographical distribution of effects found with the three doubled CO_2 climate change scenarios remained the same, with more negative or less positive effects occurring in low latitudes and more positive effects occurring at high latitudes.

The economic adjustments simulated by the BLS reflected the more benign yield changes of the GISS-A scenario (Table B-1). Global cereal production declined about 4 percent when yield estimates did not include direct CO_2 effects and increased about 2.5 percent with crop yield changes that included direct CO_2 effects. These production effects were reflected in cereal price increases of about 65 percent in the case without CO_2 effects and price decreases of about 15 percent with CO_2 effects. People at risk of hunger in developing countries (see main body of chapter for description of this index) increased about 40 percent without CO_2 effects and decreased about 10 percent with CO_2 effects.

[1] The GISS-A scenario uses a lesser amount of warming (2.4°C) than UKMO, GISS, and GFDL. It was defined as the average change in the 2030s of the GISS-A transient run and was used as a scenario for doubled CO_2 conditions. Note that the IPCC's most likely warming range is 1.5 to 4.5°C for CO_2 doubling.

Table B-1. *Change in cereal production, cereal price index, and people at risk of hunger in 2060 for GISS-A climate change scenario*

	Reference 2060	LE* (330 ppm)	LE* (555 ppm)
GLOBAL			
Cereal Production (mmt)	3286	−145	82
Cereal Price Index	121	81	−21
People at Risk** (mil)	641	265	−84
DEVELOPED			
Cereal Production (mmt)	1449	26	153
DEVELOPING			
Cereal Production (mmt)	1836	−170	−71

Notes:
* Change relative to Reference Scenario in 2060.
** In developing countries.

Testing of a climate change scenario close to the middle of the IPCC range of 1.5 to 4.5°C (IPCC, 1990a; 1992) is important to characterize more fully potential impacts on the world agricultural system. Several points are worth emphasizing with the additional perspective provided by the GISS-A scenario. First, the magnitudes of impact on world agricultural production across all scenarios tested were generally low, whether direction of change was positive or negative. Only the UKMO scenario with a high level of predicted warming (5.2°C) produced a moderate decrease in world production. However, more negative consequences to global production were simulated than positive ones, even when minor and major farm-level adaptations and lower amounts of global warming (GISS-A climate change scenario) were included. Second, the regional imbalance of effects that suggest that developing countries may be more vulnerable to climate change than developed nations occurred across all scenarios. Finally, the direction of change in global production continued to depend on the inclusion of significant beneficial physiological effects of CO_2 on crop growth and yield even in the GISS-A climate change scenario. Further research is required to lessen the uncertainties of how these effects will be manifested in farmers' fields in both temperate and tropical regions in the presence of a changing climate.

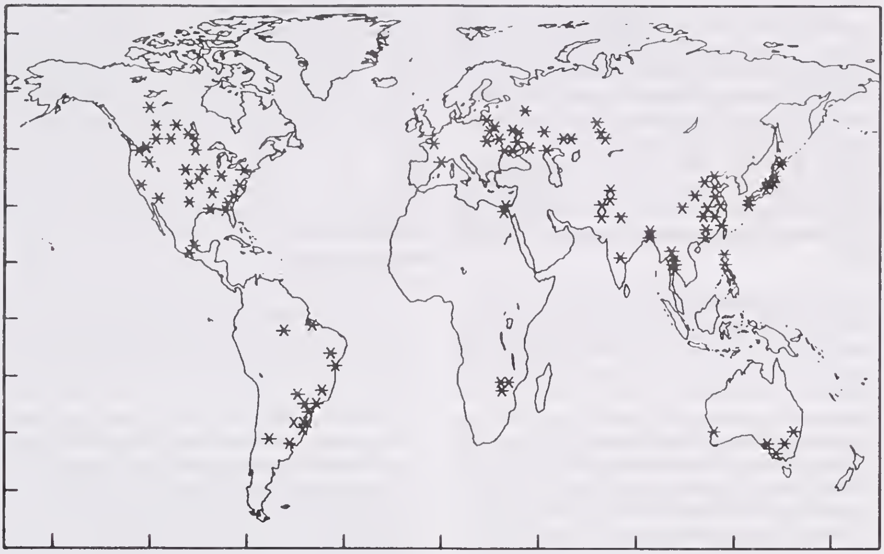

Figure 2 Crop model sites.

and irrigated crop yields. The cereal models simulate the effects of nitrogen fertilizer on crop growth, and these effects were studied in several countries in the context of climatic change. For the most part, however, the results of this study assume optimum nutrient levels.

The IBSNAT models were selected for use in this study because they have been validated over a wide range of environments (see, e.g., Otter-Nacke *et al.*, 1986) and are not specific to any particular location or soil type. They are better suited for large-area studies in which crop-growing and soil conditions differ greatly than are more detailed physiological models that have not been tested as widely. The validation of the crop models over different environments also improves the ability to estimate effects of changes in climate. Because the crop models have been tested over essentially the full range of temperature and precipitation regimes at which crops are grown in today's climate, and to the extent that future climate change is estimated to bring temperature and precipitation regimes within these ranges, the models may be considered useful tools for assessment of potential climate change impacts. Furthermore, because management practices, such as the choice of crop varieties, planting date, fertilizer application, and irrigation, may be varied in the models, they permit experiments that simulate adaptation by farmers to climatic change.

Physiological effects of CO_2

Most plants growing in experimental environments with increased levels of atmospheric CO_2 exhibit increased rates of net photosynthesis (i.e., total photosynthesis minus respiration) and reduced stomatal openings. (Experimental effects of CO_2 on crops have been reviewed by Acock and Allen [1985] and Cure [1985]). Partial stomatal closure leads to reduced transpiration per unit leaf area and, combined with enhanced photosynthesis, often improves water-use efficiency (the ratio of crop biomass accumulation or yield to the amount of water used in evapotranspiration). Recent field free-air release studies have found overall positive CO_2 effects under current climate conditions (Hendry, 1993). Thus, by itself, increased CO_2 can increase yield and reduce water use (per unit biomass).

The crop models used in this study accounted for the beneficial physiological effects of increased atmospheric CO_2 concentrations on crop growth and water use (Peart *et al.*, 1989). Ratios were calculated between measured daily photosynthesis and evapotranspiration rates for a canopy exposed to high CO_2 values, based on published experimental results (Allen *et al.*, 1987; Cure and Acock, 1986; and Kimball, 1983), and the ratios were applied to the appropriate variables in the crop models on a daily basis. The ratios (555 ppm CO_2:330 ppm CO_2) for soybean, wheat and rice, and maize were 1.21, 1.17, and 1.06, respectively. Changes in stomatal resistance were set at 49.7/34.4 s/m for C3 crops and 87.4/55.6 s/m for C4 crops, based on experimental results by Rogers *et al.* (1983). As simulated in this study, the direct effects of CO_2 may bias yield changes in a positive direction, since there is uncertainty regarding whether experimental results will be observed in the open field under conditions likely to be operative when farmers are managing crops. Plants growing in experimental settings are often subject to fewer environmental stresses and less competition from weeds and pests than are likely to be encountered in farmers' fields.

Limitations of crop growth models

The crop models embodied a number of simplifications. For example, weeds, diseases, and insect pests were assumed to be controlled; there were no problem soil conditions (e.g., salinity or acidity); and there were no extreme weather events, such as tornadoes. The models were calibrated to experimental field data, which often have yields higher than those currently typical under farming conditions. Thus, the absolute effects of climatic change on yields in farmers' fields may be different from those simulated by the crop models.

Although the crop models simulated the current range of agricultural technologies available around the world, including the use of high-yielding varieties that are responsive to technological inputs, agricultural technology is likely to be very different by the year 2060. The models may be used to test the effects of some potential improvements in agricultural production, such as the use of crop varieties with higher thermal requirements and the installation of irrigation systems, but they do not include possible future improvements. (The BLS economic model used in the study does include future trends in yield improvement, but it does not include technological developments induced by negative climate change impacts.) Finally, models for crops such as millet and cassava were not yet sufficiently tested for use in this study. Potential yield changes of such crops, which may respond differently to both climate change and increases in CO_2, are needed for better assessment of climate change impacts in tropical and subtropical regions.

Yield simulations

Crop modeling simulation experiments were performed for the baseline climate (1951–1980), values from the arbitrary sensitivity tests, and GCM doubled CO_2 climate change scenarios with and without taking into account the physiological effects of CO_2. The experiments involved the following tasks:

1. For the countries studied, geographic boundaries were defined for the major production regions; agricultural systems (e.g., rainfed and/or irrigated production, number of crops grown per year) were described; and data on regional and national rainfed and irrigated production of major crops were gathered.
2. Observed climate data for representative sites within these regions were obtained for the baseline period (1951–1980), or for as many years of daily data as were available, and the soil, crop variety, and management inputs necessary to run the crop models at the selected sites were specified.
3. The crop models were validated with experimental data from field trials, to the greatest extent possible.
4. The crop models were run with baseline data, values from the arbitrary sensitivity tests, and GCM climate change scenarios, with and without taking into account the direct effects of CO_2 on crop growth. Rainfed and/or irrigated simulations were carried out as appropriate to current growing practices.
5. Alterations in farm-level agricultural practices that would lessen any adverse consequences of climate change were identified and evaluated by simulating irrigated production and other adaptation responses (for example, shifts in planting date and substitution of crop varieties).

Table 3. *Current world crop yield, area, production, and percent world production aggregated for countries participating in study*

Crop	Yield (t/ha)	Area (ha × 1000)	Production (t × 1000)	Study countries (%)
Wheat	2.1	230,839	481,811	73
Rice	3.0	143,603	431,585	48
Maize	3.5	127,393	449,364	71
Soybeans	1.8	51,357	91,887	76

Source: FAO, 1988.

Deriving estimates of potential crop yield changes

Aggregation of site results

Table 3 shows the percentages of world production of wheat, rice, maize, and soybean for the countries in which simulations were conducted. Simulations were carried out in regions representing 70–75 percent of the current world production of wheat and maize. Even though model runs for soybean were conducted in only two countries (Brazil and the United States), these together account for 76 percent of world production. Rice production was less well represented in the model simulations than the other crops, because India, Indonesia, and Vietnam have significant production areas that were not included in the study. Further research is needed in these key countries in order to improve the reliability of the projections of climate change impacts on rice production.

Crop model results for wheat, rice, maize, and soybean from the 112 sites in the 18 countries were aggregated by weighting regional yield changes (based on current production) to estimate changes in national yields. The aggregations were either calculated by the participating scientists or developed jointly with them (see Rosenzweig and Iglesias, 1994). The scientists in each country selected sites representative of major agricultural regions, described the regional agricultural practices, and provided production data for the estimation of regional contributions to the national yield changes. Other crop production data sources included the United Nations Food and Agriculture Organization (FAO, 1988), the U.S. Department of Agriculture (USDA) Crop Production Statistical Division, and the USDA International Service. The regional yield estimates represented the current mix of rainfed and irrigated production and the current crop varieties, nitrogen management, and soil types.

Table 4. *Increments added to estimated yield change to account for direct effects of CO_2*

Crop	Percentage[1]
Wheat	22
Rice	19
Soybeans	34
Coarse grains[2]	7
Other C3 crops	25
Other C4 crops	7

Notes.
[1] Based on crop model simulations.
[2] Weighted by relative production of C3 and C4 crops constituting coarse grain production in the particular country or region.

Yield change estimates for crops and regions not simulated
Changes in national yields of other crops and commodity groups and for regions not simulated were estimated based on three criteria: (1) similarities to growing conditions for the modeled crops, (2) results from approximately 50 previously published and unpublished regional climate change impact studies (AIR Group unpublished manuscript), and (3) projected temperature and precipitation changes (and hence soil moisture availability for crop growth) from the GCM climate change scenarios.

Estimates of yield changes were made with and without taking into account the direct effects of CO_2. Increments added to the estimated crop yield changes to account for direct CO_2 effects were based on average responses of crop production to CO_2 and climate change scenarios in the crop model simulations (Table 4). These increments differ from the photosynthesis ratios employed in the crop models because they incorporate the combined responses of the simulated crops to changes in photosynthesis and evapotranspiration as well as to changes in climate. In the crop model simulations, the responses to CO_2 did not vary greatly across regions and climate change scenarios.

Limitations of crop yield change estimates
The primary source of uncertainty in the estimates lay in the sparseness of the crop modeling sites and the fact that they may not have adequately represented the variability of agricultural regions within countries, the variability of agricultural systems within similar agro-ecological zones, or dissimilar agricultural regions. However, since the study sites were similar to regions that account for about 70 percent of world grain production, the conclusions concerning world totals of cereal production contained in this study are believed to be adequately substantiated. Another source of uncertainty lay in the simulation of grain crops only, leading to the estimation of yield changes for other commodities, such as root crops and fruit, based primarily on previous estimates. The previous estimates tended to be less negative than the crop responses modeled in this study, and this introduced a bias in favor of these other crops in the world food trade model.

Farm-level adaptations
In each country, the agricultural scientists used the crop models to test possible responses to the worst climate change scenario (which was usually, but not always, the UKMO scenario). These adaptations included changes in planting date, cultivar, amounts of irrigation, fertilizer use, and crop variety. Irrigation simulations in the crop models assumed automatic irrigation to field capacity when plant available water dropped to 50 percent and 100 percent irrigation efficiency. All adaptation possibilities were not simulated at every site and country: the choice of adaptations to be tested was made by the participating scientists, based on their knowledge of current agricultural systems (Table 5).

For the economic analysis in the BLS, the crop model results reported by the participating scientists were grouped into two levels of adaptation. Adaptation Level 1 implied little change to existing agricultural systems, reflecting relatively easy farmer response to a changing climate. Adaptation Level 2 implied more substantial change to agricultural systems, possibly requiring resources beyond the farmer's means.

Adaptation Level 1 included:

1. Shifts in planting date (± 1 month)
2. Additional application of irrigation water to crops already under irrigation

Table 5. *Adaptations tested in crop modeling study*

Country	Crop tested[a]	Change of planting date	Change of cultivar/crop	Additional irrigation	Additional N fertilizer
Argentina	m	x	x[1,7]	x	
Australia	r,w	x[2]	x	x[2]	
Bangladesh	r		x		
Brazil	w,m,s	x[2]	x[1]	x,x[2,3]	x
Canada	w	x[6]		x,x[2]	
China	r	x	x,x[5,7]		
Egypt	m,w	x	x	x	
France	m,w	x,x[7]	x	x	
India	w			x	
Japan	r,w,m	x[2]		x[2]	
Mexico	m	x	x[1]	x[3]	x
Pakistan	w	x		x	
Philippines	r	x[5]	x[5]		
Thailand	r		x		
Uruguay	b	x	x	x	x,x[4]
USA	w,m,s	x	x	x	
USSR	w	x[6,7]	x		
Zimbabwe	m	x[2]		x,x[2]	x

Notes:
[a]w = wheat; m = maize; r = rice; s = soybean; b = barley
[1] Hypothetical new cultivar.
[2] Combination of irrigation and change in planting date.
[3] Combination of irrigation and increased nitrogen fertilizer.
[4] Combination of change in planting date and increased nitrogen fertilizer
[5] Combination of new cultivar and change in planting date.
[6] Change to winter wheat.
[7] Suggested shift in the zone of crop production.

3. Changes in crop variety to currently available varieties more adapted to the altered climate

Adaptation Level 2 included:

1. Large shifts in planting date (> 1 month)
2. Increased fertilizer application (included here because of the implied costs for farmers in developing countries)
3. Installation of irrigation systems
4. Development of new crop varieties (tested by the manipulation of genetic coefficients in crop models)

Yield changes for both adaptation levels were based on crop model simulations where available and extended to other crops and regions using the estimation methods described above. For the crops and regions not simulated, the negative impact of climate change was halved if adaptations were estimated to partially compensate for them; if compensation was estimated to be full, yield changes were set to 0. If yield changes were positive in response to climate change and the direct effects of CO_2, adaptation to produce even greater yield increases was not included, with the assumption that farmers would lack incentive to adapt further. The adaptation estimates were developed only for the scenarios that included the direct effects of CO_2, as these were judged to be most realistic. Examples of the crop yield change estimates for Adaptation Levels 1 and 2 for the UKMO climate change scenario for several countries are shown in Table 6.

Limitations of the adaptation analysis

The adaptation simulations were not comprehensive, because all possible combinations of farmer responses were not tested at every site. Spatial analyses of crop, climatic, and soil resources are needed to fully test the possibilities for crop substitution. Neither the availability of water supplies for irrigation nor the costs of adaptation were considered in this study; these are both critical needs for further research. A related study on the integrated impacts of climate change in Egypt, which utilized the results of this work, does address future water availability for national agricultural production in that country (see Chapter 7)

At the local level, there may be social or technical reasons

Table 6. *Changes in wheat yield[1] estimated for the UKMO $2 \times CO_2$ climate change scenario, alone and with two levels of farm adaptation*

	UKMO (%)	AD1[2] (%)	AD2[3] (%)
Argentina	−30	−20	−10
USA	−14	−7	−3
Eastern Europe & former USSR	−20	−10	−5

Notes

[1] With direct CO_2 effects.

[2] Adaptation Level 1 implies minor change to current agricultural systems.

[3] Adaptation Level 2 implies major change to current agricultural systems.

why farmers are reluctant to implement adaptation measures. For example, increased fertilizer application and improved seed stocks may be capital-intensive and not suited to indigenous agricultural strategies. Furthermore, such measures may not necessarily result in sustainable production increases. In the case of irrigation, initial benefits may eventually give way to soil salinization and lower crop yields. Thus, Adaptation Level 2 represents a fairly optimistic assessment of world agriculture's response to changed climate conditions as characterized by the GCMs tested in this study and may possibly require substantial changes in current agricultural systems, investment in regional and national agricultural infrastructure, and policy changes. However, estimation of the effect of changes in regional, national, and international agricultural policies relating to farm-level adaptation were beyond the scope of the analysis.

The world food trade model

The world food system is a complex, dynamic interaction of producers and consumers, mediated through global markets. Related activities include input production and acquisition, transportation, storage, and processing. Although there is a trend toward internationalization in the world food system, only about 15 percent of the total world agricultural production currently crosses national borders (Fischer *et al.*, 1990). National governments shape the system by imposing regulations and by making investments in agricultural research, infrastructure improvements, and education. The system functions to meet the demand for food, to produce food in increasingly efficient ways, and to trade food within and across national borders. Although the system does not guarantee stability, it has generated long-term real declines in prices of major food staples (Fischer *et al.*, 1990).

The Basic Linked System consists of linked national agricultural sector models. It was designed at IIASA for food policy studies, but it also can be used to evaluate the effect of climate-induced changes in crop yield on world food supply and agricultural prices. It consists of 16 national (including the European Community [EC]) models with a common structure, 4 models with country-specific structures, and 14 regional group models (Table 7). The 20 models in the first two groups cover about 80 percent of attributes of the world food system, such as demand, land, and agricultural production. The remaining 20 percent are covered by the 14 regional models for countries that have broadly similar attributes (e.g., African oil-exporting countries, Latin American high-income exporting countries, Asian low-income countries, etc.). The grouping is based on country characteristics, such as geographic location, income per capita, and the country's position with regard to net food trade.

The BLS is a general equilibrium model system, with representation of all economic sectors, empirically estimated parameters, and no unaccounted supply sources or demand sinks (see Fischer *et al.* [1988] for a complete description of the model). In the BLS, countries are linked through trade, world market prices, and financial flows (Figure 3). It is a recursively dynamic system: a first round of exports from all countries is calculated for an assumed set of world prices, and international market clearance is checked for each commodity. World prices are then revised, using an optimizing algorithm and are again transmitted to the national models. Next, new domestic equilibria are generated and net exports are adjusted. This process is repeated until the world markets for all commodities are cleared. At each stage of the iteration, domestic markets are in equilibrium. This process yields international prices as influenced by governmental and intergovernmental agreements. The system is solved in annual increments, simultaneously for all countries. Summary indicators of the sensitivity of the world system include world cereal production, world cereal prices, and prevalence of population in developing countries at risk of hunger.

The BLS does not incorporate any climate relationships per se. Effects of changes in climate were introduced to the model as changes in the average national or regional yield per commodity. Ten commodities were included in the model: wheat, rice, coarse grains, protein feed, bovine and ovine meat, dairy products, other animal products, other food, non-food agriculture, and non-agriculture. Yield change estimates for coarse grains were based on the percentage of maize grown in the country or region; soybean crop model results were used to estimate the protein feed category; and the estimates for the non-grain crops were based on the modeled grain crops and previous estimates of climate

Table 7 *Models in the Basic Linked System*

Models with a common structure	Models with country-specific structures	Regional group models
Argentina	Eastern Europe & former USSR	Africa Oil Exporters
Australia	China	Africa Medium-Income Exporters
Austria	India	Africa Medium-Income Importers
Brazil	United States	Africa Low-Income Exporters
Canada		Africa Low-Income Importers
Egypt		Latin American High-Income Exporters
Indonesia		Latin American High-Income Importers
Japan		Latin American Medium Income
Kenya		Southeast Asia High-Medium Exporters
Mexico		Southeast Asia High-Medium Importers
Nigeria		Asia Low Income
New Zealand		Southwest Asia Oil Exporters
Pakistan		Southwest Asia Medium-Low Income
Thailand		Rest of the World
Turkey		
European Community		

Note: See Appendix 3 for countries within regional groups.

change impacts as described above. A positive bias toward non-grain crops was introduced by this procedure, since the previous estimates of yield changes of the non-grain crops were less negative than the modeled results from this study.

Economic growth rates

Economic growth rates are a product of several BLS functions. Non-agricultural production utilizes a Cobb Douglas production function, with labor and capital as production factors. Non-agricultural labor input depends primarily on population growth and somewhat on relative prices between agriculture and non-agriculture by means of a sector migration function. Capital accumulation depends on investment and depreciation, which in turn depend on rates of saving and depreciation. Depreciation rates and rates of saving were estimated from historical data and were kept constant after 1990. There was an exogenous assumption based on historical data for technical progress in the production function. For the lower growth scenario, the rate of saving was reduced, resulting in about 10 percent lower gross domestic product in 2060.

The economic growth rates predicted by the BLS in the reference case followed historical trends, as shown in Table 8. For the period 1980 to 2060, the BLS predicted a growth of 1.3 percent, 1.7 percent, and 2.4 percent annually for world, developed, and developing countries, respectively, as compared to average population growth rates of 1.1 percent, 0.3 percent, and 1.3 percent.

Yield trends

In general, the rate of exogenous technical progress started from historical values and for cereal crops approached 0.5 percent per annum by 2060. Representing improvement in agriculture productivity due to technological progress, the annual yield trends used in the BLS for the period 1980–2000 were 1.2 percent, 1.0 percent, and 1.7 percent for world, developed countries, and developing countries, respectively. According to FAO data, yields have been growing at an average of around 2 percent annually during the period 1961–1990, both for developed and developing (excluding China) countries (FAO, 1991). From 1965 to 1985, annual productivity for less-developed countries grew at about 1.5 percent/year. In the 1980s, however, yields grew globally by an average of only 1.3 percent, implying a falling trend in yield growth rates.

The falling growth rates utilized in the reference case of the BLS may be justified for several reasons. Historical trends suggest decreasing rates of increase in crop yields, and yield improvements from biotechnology have yet to be realized. Much of the large yield increases in developed countries in the 1950s and 1960s and in developing countries thereafter was due to the intensification of chemical inputs and mechanization. Apart from economic reasons and environmental concerns, which suggest that maximum input levels may have been reached in many developed countries, there are likely to be diminishing rates of return for further input increases. In some developing countries, especially in Africa, increase in input levels and intensification of production are likely to continue for some time but may also ultimately level off. Furthermore, since Africa has the lowest average cereal yields of all the regional groups combined with a high population growth rate, it will likely contribute an increasing share of cereal production, thereby reducing average global yield increases.

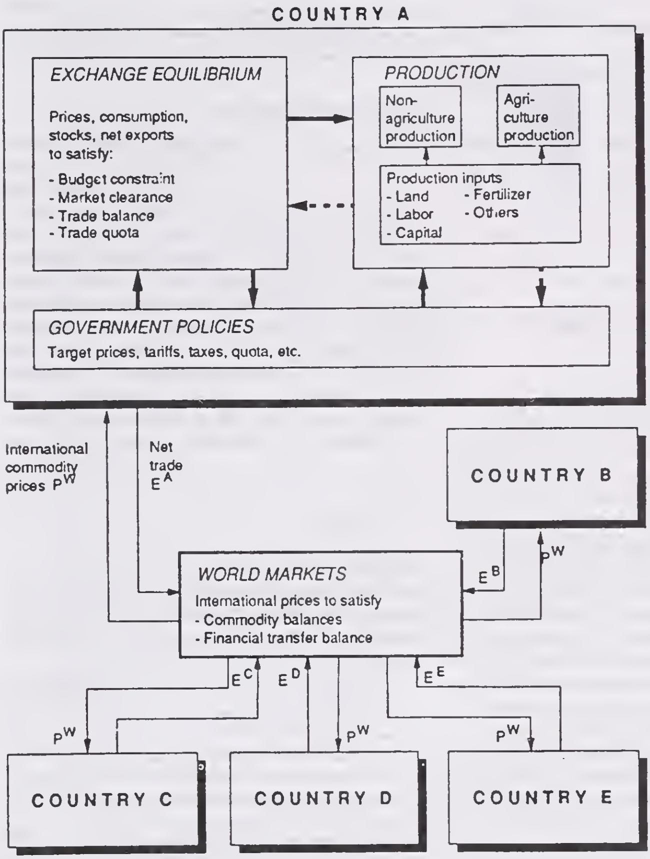

Figure 3 The Basic Linked System: relationships between country components and world markets. Arrows to countries represent international commodity prices; arrows to world markets represent net trade.

Arable land

Estimates of the availability of arable land for expansion of crop production were based on FAO data. In the BLS standard national models, a piece-wise linear time-trend function was used to impose upper bounds (inequality constraints) on land use. In addition, this time-trend function was modified with an elasticity term (usually 0.05 or less) which reacts to changes in shadow prices of land in comparison to 1980 levels. The upper limits imposed by the time-trend function utilized the FAO data on potential arable land. The arable land limits were not adjusted for climate change even though they may be affected positively in some locations by an extension of season length or a drying of wet soils, or negatively by sea-level inundation or desertification.

Risk of hunger indicator

The indicator of the number of people at risk of hunger used in the BLS was defined as those people in developing countries (excluding China) with an income insufficient to either produce or procure their food requirements. The measure was derived from FAO estimates and methodology for developing market economies (FAO, 1984 and 1987). The FAO estimates were obtained by stipulating that calorie consumption distribution in a country is skewed and can be

Table 8. *Historical and simulated average annual growth rates of GDP (% per annum)*

	Historical				Basic Linked System		
	1960 to 1970	1970 to 1980	1980 to 1990	1980 to 2000	2000 to 2020	2020 to 2040	2040 to 2060
World	4.8	3.6	2.9	2.9	2.0	1.5	1.1
Developed countries	4.7	3.1	2.8	2.6	1.8	1.3	1.0
Developing countries	5.2	5.4	3.1	4.0	2.6	1.8	1.3

Source: FAO, 1991.

represented by a beta distribution. The parameters of these distributions were estimated by the FAO for each country based on country-specific data and cross-country comparisons. The estimate of the energy requirement of an individual was based on the basal metabolic rate (time in a fasting state and lying at complete rest in a warm environment). Body weight, age, and sex have an impact on this requirement. The FAO presented two estimates of the number of undernourished people, based on minimum maintenance requirements of 1.2 and 1.4 (the latter judged as more appropriate) basal metabolic rate. The BLS estimate for 1980, based on the 1.4 basal metabolic rate requirements, was 501 million undernourished people in the developing world, excluding China.

Limitations of the world food trade model

The economic adjustments simulated by the BLS were assumed not to alter the basic structure of the production functions. These relationships may be altered in a changing climatic regime and under conditions of elevated CO_2. For example, yield responses to nitrogen fertilization may be altered due to changing nutrient solubilities in warmer soils. Furthermore, in the analysis of BLS results, consideration was limited to the major cereal food crops, even though shifts in the balance of arable land and livestock agriculture are also likely under changed climatic regimes. Livestock production is a significant component of the global food system and is also potentially sensitive to climatic change. The non-agriculture sector was poorly modeled in the BLS, leading to simplifications in the simulation of economic responses to climatic change.

Finally, recent changes in global geopolitics and related changes in agricultural production were not well represented in the BLS. To account for these changes, prices in previously planned economies were made more responsive compared to earlier versions, 'plan targets' for allocation decisions were replaced, and some constraints were relaxed in the agricultural sector model. Better analysis depends on the development of new models for these emerging capitalist economies.

The set of model experiments

The estimates of climate-induced changes in food production potential were used as inputs to the BLS in order to assess possible impacts of climate change on future levels of food production, food prices, and the number of people at risk of hunger (see Figure 1). Impacts were assessed for the year 2060, with estimates of population growth, technology trends, and economic growth projected to that year. Assessments were first made for a reference scenario that assumed no climate change and were subsequently made for the GCM scenarios (see discussion above). The difference between the two assessments is the climate-induced effect. A further set of assessments examined the efficacy of two levels of farmer adaptation in mitigating climate change impacts and the effect on future production of different rates of economic and population growth, and of liberalizing the world trade system. Results for these scenarios are described in the following sections.

THE REFERENCE SCENARIO

The reference scenario projected the agricultural system to the year 2060, assuming no climate change and no major changes in the political or economic context of world food trade. It assumed:

- UN medium population estimates (10.2 billion people by 2060) (International Bank for Reconstruction Development/World Bank, 1990)
- 50 percent trade liberalization in agriculture (e.g., removal of import restrictions), introduced gradually by 2020.
- Moderate economic growth (ranging from 3.0 percent/year in 1980–2000 to 1.1 percent/year in 2040–2060).
- Technology projected to increase yields over time (1990–2060). Cereal yields for the world, developing countries, and developed countries were assumed to increase annually by 0.7 percent, 0.9 percent, and 0.6 percent, respectively.

CLIMATE CHANGE SCENARIOS

These are projections of the world system, including effects of climate change on agricultural yields under the GCM scenarios. The food trade simulations for these three scenarios began with 1990 and assumed a linear change in yields until the doubled CO_2 changes would be reached in 2060. Simulations were made both with and without taking into account the physiological effects of 555 ppm CO_2 on crop growth and yield for the equilibrium yield estimates. In these scenarios, internal economic adjustments in the model occur, such as increased agricultural investment, reallocation of agricultural resources according to economic returns (including crop switching), and reclamation of additional arable land as a response to higher cereal prices. These are based on shifts in supply and demand factors that alter the comparative advantage among countries and regions in the world food trade system. These economic adjustments are assumed not to feed back to the yield levels predicted by the crop modeling study.

SCENARIOS INCLUDING THE EFFECTS OF FARM-LEVEL ADAPTATIONS

The food trade model was first run with yield changes assuming no external farm-level adaptation to climate change and was then re-run with different climate-induced changes in yield projected from the two levels of adaptation described above. Policy, cost, and water resource availability were not studied explicitly and were assumed not to be barriers to adaptation. Switching from one enterprise to another based on production and demand factors was included in the BLS

SCENARIOS OF DIFFERENT FUTURE TRADE POLICIES AND DIFFERENT LEVELS OF ECONOMIC AND POPULATION GROWTH

A final set of scenarios assumed changes to the world tariff structure and different rates of economic and population growth, yielding insight into alternate futures. As with the previous experiments, these were conducted both with and without taking climate change into account. These scenarios included.

- *Trade liberalization*, with full trade liberalization in agriculture being introduced gradually by 2020.
- *Slower rates of economic growth*, ranging from 2.7 percent/year in 1980–2000 to 1.0 percent in 2040–2060. Such low rates would result in a global GDP in 2060 that would be 10.3 percent lower than the reference scenario and would be 11.2 percent lower in developing countries and 9.8 percent lower in developed countries.
- *Low population growth*, following UN low population estimates (8.6 billion people by 2060).

The analysis of trade liberalization in this study was restricted to the removal of distortions between trade prices and domestic prices at the level of the raw materials of the agricultural commodities. Where applicable, trade and production quotas were released. Other types of domestic assistance, e.g., input subsidies, export credit, and insurance, were not included in the analysis. For a given world market price for an agricultural commodity, the domestic price under trade liberalization depends upon whether the country is a net exporter or net importer of the commodity, the differential being a margin for international freight and insurance.

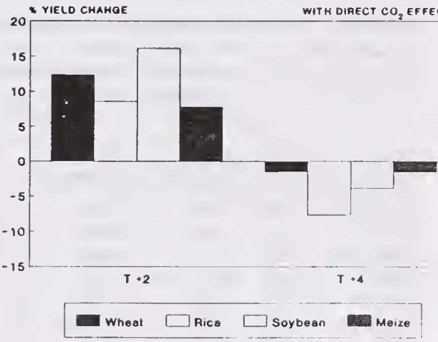

Figure 4 Aggregated IBSNAT crop model yield changes for +2°C and +4°C temperature increase. Country results are weighted by contribution of national production to world production. Direct effects of CO_2 on crop growth and water use are taken into account.

EFFECTS ON CROP YIELDS

Crop yields with arbitrary sensitivity tests

With the direct effects of CO_2 and precipitation held at current levels, average crop yields weighted by national production showed a positive response to +2°C warming and a negative response to +4°C (Figure 4). Wheat and soybean yields were estimated to increase 10–15 percent, and maize and rice yields were estimated to increase about 8 percent, with a +2°C temperature rise. Yields of all four crops turn negative at +4°C, indicating a threshold of the compensation of direct CO_2 effects for temperature increases between 2 and 4°C, as simulated in the IBSNAT crop models. Rice and soybean would be most negatively affected at +4°C. These averaged results, however, mask differences among countries. For example, the effects of latitude are such that in Canada, a +2°C temperature increase with no precipitation change would result in wheat yield increases (with direct effects of CO_2 taken into account), whereas the same changes in Pakistan would result in average wheat yield decreases of about 12 percent. In general, a 20 percent increase in precipitation would improve the simulated yields of the crops tested, and a 20 percent decrease would lower yields of all crops.

Crop yields without adaptation

Table 9 shows modeled wheat yield changes for the GCM doubled CO_2 climate change scenarios (the yield changes include results from both rainfed and irrigated simulations,

Table 9. *Current production and change in simulated wheat yield under GCM 2 × CO_2 climate change scenarios, with and without accounting for the direct effects of CO_2*[1]

	Current production				Change in simulated yields					
					Without CO_2			With CO_2		
Country	Yield (t/ha)	Area (ha × 1000)	Prod. (t × 1000)	% Total	GISS[2] (%)	GFDL[2] (%)	UKMO[2] (%)	GISS[3] (%)	GFDL[3] (%)	UKMO[3] (%)
Australia	1.38	11,546	15 574	3.2	−18	−16	−14	8	11	9
Brazil	1.31	2,788	3,625	0.8	−51	−38	−53	−33	−17	−34
Canada	1.88	11,365	21,412	4.4	−12	−10	−38	27	27	−7
China	2.53	29,092	73,527	15.3	−5	−12	−17	16	8	0
Egypt	3.79	572	2,166	0.4	−36	−28	−54	−31	−26	−51
France	5.93	4,636	27,485	5.7	−12	−28	−23	4	−15	−9
India	1.74	22,876	39,703	8.2	−32	−38	−56	3	−9	−33
Japan	3.25	237	772	0.2	−18	−21	−40	−1	−5	−27
Pakistan	1.73	7,478	12,918	2.7	−57	−29	−73	−19	31	−55
Uruguay	2.15	91	195	0.0	−41	−48	−50	−23	−31	−35
Former USSR										
winter	2.46	18,988	46,959	9.7	−3	−17	−22	29	9	0
spring	1.14	36,647	41,959	8.7	−12	−25	−48	21	3	−25
USA	2.72	26,595	64,390	13.4	−21	−23	−33	−2	−2	−14
WORLD[4]	2.09	231	482	72.7	−16	−22	−33	11	4	−13

Notes:

[1] Results for each country represent the site results weighted according to regional production The world estimates represent the country results weighted by national production. Sources: see Appendix 2.

[2] GCM 2 × CO_2 climate change scenario alone.

[3] GCM 2 × CO_2 climate change scenario with direct CO_2 effects.

[4] World area and production × 1,000,000.

weighted by current percentage of the respective practice). When the direct physiological effects of CO_2 were not taken into account, climate changes caused decreases in simulated wheat yields in all cases; when accounted for, the direct effects of CO_2 mitigated the negative effects primarily in mid- and high latitudes.

The magnitudes of the estimated yield changes varied by crop (Table 10 and Figure 5, Plate I). Global wheat yield changes weighted by national production were positive with the direct CO_2 effects in two out of three scenarios, while maize yield was most negatively affected, reflecting its greater production in low-latitude areas where simulated yield decreases were greater. Of all of the crops, maize production declined most with direct CO_2 effects, probably due to its lower response to the physiological effects of CO_2. Simulated soybean yields were most reduced without the direct effects of CO_2 but were least affected in the less severe GISS and GFDL climate change scenarios when direct CO_2 effects were simulated. Soybean responded positively to increased CO_2, but it is the crop most affected by the high temperatures of the UKMO scenario.

The differences among countries in simulated crop yield responses to climate change when the direct effects of CO_2

Table 10. *Changes in simulated wheat, rice, maize, and soybean yield*

	Change in simulated yields[1]					
	Without CO_2			With CO_2		
Crop	GISS[2] (%)	GFDL[2] (%)	UKMO[2] (%)	GISS[3] (%)	GFDL[3] (%)	UKMO[3] (%)
Wheat	−16	−22	−33	11	4	−13
Rice	−24	−25	−25	−2	−4	−5
Maize	−20	−26	−31	−15	−18	−24
Soy	−19	−25	−57	16	5	−33

Notes.

[1] Crop yield changes were obtained by weighting site results first by regional production within countries and then by national contribution to total production simulated in the study. Sources: see Appendix 2.

[2] GCM climate change scenario alone.

[3] GCM climate change scenario with direct effects of CO_2.

were not taken into account were primarily related to differences in current growing conditions. Higher temperatures tended to shorten the growing period at all locations tested. At low latitudes, however, crops are currently grown at higher temperatures, produce lower yields, and are nearer the limits of temperature tolerances for heat and water stress. Warming at low latitudes thus results in accelerated growing periods for crops, more severe heat and water stress, and greater yield decreases than at higher latitudes. In many mid- and high-latitude areas, where current temperature regimes are cooler, increased temperatures, although still shortening grain-filling periods, thus exerting a negative influence on yields, do not significantly increase stress levels. At some sites near the high-latitude boundaries of current agricultural production, increased temperatures can benefit crops otherwise limited by cold temperatures and short growing seasons.[1] The potential for expansion of cultivated land is embedded in the BLS world food trade model and is reflected in shifts in production calculated by that model.

Simulated yield increases in the mid- and high latitudes were caused primarily by:

1. *Positive physiological effects of CO_2.* At sites with cooler initial temperature regimes, increased photosynthesis more than compensated for the shortening of the growing period caused by warming.
2. *Lengthened growing season and amelioration of cold temperature effects on growth.* At some sites near the high-latitude boundaries of current agricultural production, increased temperatures extended the frost-free growing season and provided regimes more conducive to greater crop productivity.

The primary causes of decreases in simulated yields were:

1. *Shortening of the growing period.* Higher temperatures during the growing season speed annual crops through their development (especially at the grain-filling stage), allowing less grain to be produced. This was projected to occur in most crops and sites, one exception being those sites with the coolest growing season temperatures in Canada and the former USSR.
2. *Decrease in water availability.* This factor is the result of a combination of increases in evapotranspiration rates in the warmer climate enhanced losses of soil moisture, and, in some cases, a projected decrease in precipitation in the climate change scenarios.
3. *Poor vernalization.* Vernalization is the requirement of some temperate cereal crops, e.g., winter wheat, for a period of low winter temperatures to initiate or accelerate the flowering process. Low vernalization results in low flower bud initiation and, ultimately, in reduced yields. Projected decreases in winter wheat yields at some sites in Canada and the former USSR were due to lack of vernalization.

[1] The extent of soil suitable for expanded agricultural production in these regions was not studied explicitly.

Figure 6 (Plate 2) shows estimated potential changes in average national grain crop yields for the GISS, GFDL, and UKMO doubled CO_2 climate change scenarios with and without allowing for the direct effects of CO_2 on plant growth. The maps were created from the nationally averaged yield changes for wheat, rice, coarse grains, and protein feed estimated for the BLS simulations for each country or group of countries in the world food trade model; regional variations within countries are not reflected. Latitudinal differences are apparent for all the scenarios. With direct CO_2 effects, high-latitude changes are less negative or even positive in some cases, whereas lower-latitude regions suffer more detrimental effects of climate change on agricultural yields.

The GISS and GFDL climate change scenarios, with CO_2 effects on crop growth and water use, produced yield changes ranging from +30 to −30 percent. Effects on crop yields under the GISS scenario were, in general, more adverse than under the GFDL scenario for parts of Asia and South America, while effects under the GFDL scenario resulted in more negative yields in the United States and Africa and less positive results in the former USSR. The UKMO climate change scenario, which had the greatest warming (5.2°C global surface air temperature increase), showed average national crop yields to decline almost everywhere (by up to 50 percent in Pakistan) even with beneficial CO_2 effects taken into account.

Crop yields with adaptation

The adaptation studies conducted by the scientists participating in the project suggest that ease of adaptation to climate change is likely to vary with crop, site, and adaptation technique (Table 11). For example, at present, many Mexican producers can afford to use only small doses of nitrogen fertilizer at planting; if more fertilizer becomes available to more farmers, some of the yield reductions under the climate change scenarios might be offset. However, given the current economic and environmental constraints in countries such as Mexico, a future with unlimited water and nutrients is unlikely (Liverman *et al.*, 1992). In contrast, switching from spring to winter wheat at the modeled sites in the former USSR would produce a favorable response (Menzhulin *et al.*, 1992), suggesting that agricultural productivity may be enhanced there with the relatively easy shift to winter wheat varieties.

Yield estimates for the two levels of adaptation developed for the BLS simulations for the GCM scenarios are shown in Figure 7 (Plate 3). As in Figure 6 (Plate 2), results shown are averages for countries and groups of countries, and regional variations within countries are not reflected. Direct CO_2 effects on crop growth and water use are taken into account. Adaptation Level 1, simulating minor changes to existing agricultural systems, compensated for the climate change

Table 11. *Adaptation tests in Mexico and the former USSR*

A. Effect of GCM 2 × CO_2 climate change scenarios on CERES-Maize yields at Tlaltizapan and Poza Rica, Mexico, with and without nutrient stress.

	Simulated yield[1] (t/ha)			
	Nutrient stress[2]		No nutrient stress	
Scenario	Tlaltizapan	Poza Rica	Tlaltizapan	Poza Rica
BASE	4.02	3.18	4.49	3.98
GISS	3.07	2.97	3.77	3.30
GFDL	3.20	2.70	3.47	3.18
UKMO	1.56	2.35	3.93	2.67

B. Effect of GCM 2 × CO_2 climate change scenarios on aggregated spring and winter CERES-Wheat yield in the former USSR

	Simulated yield change[1] (%)	
Scenario	Spring wheat	Winter wheat
GISS	+21	+41
GFDL	−4	+12
UKMO	−18	+9

Notes:
[1] With direct CO_2 effects
[2] Actual conditions.

scenarios incompletely, particularly in the developing countries. For the GISS and GFDL scenarios, adaptation implying major changes to current agricultural systems (Adaptation Level 2) compensated almost fully for the negative climate change impacts. With the high level of global warming from the UKMO climate change scenario, neither Level 1 nor Level 2 Adaptation fully overcame the negative climate change effects on crop yields in most countries, even when direct CO_2 effects were taken into account.

EFFECTS OF CLIMATE CHANGE ON FOOD PRODUCTION, FOOD PRICES, AND RISK OF HUNGER

The reference scenario (the future without climate change)

Assuming no effects of climate change on crop yields and current trends in economic and population growth rates, the models predicted world cereal production[2] to be 3,286 million metric tons (mmt) in 2060 (compared to 1,795 mmt in 1990). Per capita cereal production in developed countries would increase from 690 kg per capita in 1980 to 984 kg per capita in 2060. In developing countries (excluding China) cereal production would increase from 179 to 282 kg per capita. Aggregated world per capita cereal production would decrease from 327 kg per capita in 1980 to 319 kg per capita in 2060. The declining aggregate trend for the future is caused by the relatively large difference in per capita cereal production in the developed and developing countries and the demographic changes assumed by the model.

Cereal prices were estimated at an index of 121 (1970 = 100) for the year 2060, reversing the trend of falling real cereal prices over the last 100 years (Table 12). This increase occurred because the BLS standard reference scenario had two phases of price development. During 1980 to 2020, while trade barriers and protection are still in place but are being reduced, there would be increases in relative prices; price decreases would follow when trade barriers are removed. The number of hungry people was estimated at about 640 million, or about 6 percent of total population in 2060 (compared to 530 million in 1990, about 10 percent of the total current population).

Table 12. *Index of world prices simulated by the Basic Linked System reference case (1970 = 100)*

	Year			
	1980	2000	2020	2060
Cereals	102	125	126	121
Other crops	110	118	110	94
All crops	108	120	115	102
Livestock	105	131	135	119
Agriculture	107	123	121	107

Effects of climate change with and without adjustments in the economic system

The BLS included the ability to simulate adjustments that the world food system might make to changes of yield (e.g., reallocation of agricultural land use, change in fertilizer use, and application of irrigation water). Simulations of the effects of climate change without such internal adjustments were of theoretical interest only as these would unrealistically imply no economic or behavioral response of producers and consumers. However, these hypothetical impacts help to define the adjustments taking place in the system over time. Under these conditions the effects of climate change and increased atmospheric CO_2 on crop yields derived from the GCM scenarios imply a 5 percent to an almost 20 percent reduction in total cereal production (Table 13). These esti-

[2] The estimate for cereals includes wheat, rice, maize, millet, sorghum, and minor grains (FAO, 1991); rice is included as rice milled equivalent (a factor of 0.67 is used to convert from rice paddy to milled rice).

Table 13. *Resilience[1] of the current food system to GCM climate change scenarios*

Cereal production[2]	GISS (%)	GFDL (%)	UKMO (%)
Without adjustment	−5.3	−8.5	−18.5
With adjustment	−1.2	−2.8	−7.6

Notes

[1] Effect on world cereal production (percent change from reference) assuming economic adjustments/no economic adjustments (e.g., in land area, fertilizer use, and irrigation) simulated by the Basic Linked System.

[2] With direct CO_2 effects.

mates are changes to production levels projected for 2060 without climate change.

Adjustments within the economic system without the adaptation discussed above would tend to counteract negative yield impacts as agricultural production shifts to regions of more favorable comparative advantage. Such economic adjustment includes expansion of production in favorable areas and reduction of output in areas that become less productive. The BLS offset 65–80 percent of the potential impact on yield in scenarios for impacts below 10 percent of global cereal production (the GISS and GFDL climate change scenarios). The offset decreased to 60 percent under a scenario of greater yield reduction (UKMO).

Table 14 *Changes in cereal production, cereal prices, and number of people at risk of hunger in 2060 under GCM 2 × CO_2 climate change scenarios*

A. Change in cereal production

Region	Reference scenario[1]	GISS (%)	GFDL (%)	UKMO (%)
Global	3286	−1.2	−2.8	−7.6
Developed	1449	11.3	5.2	−3.5
Developing[2]	1836	−11.0	−9.2	−10.8

B. Change in cereal price index (1970 = 100)

	Reference scenario[1]	GISS (%)	GFDL (%)	UKMO (%)
Cereal prices	121	24	33	145

C. Change in number of people at risk of hunger

Region	Reference scenario[1]	GISS (%)	GFDL (%)	UKMO (%)
Developing[2]	641	10	17	58

Notes

[1] Reference scenario is for 2060 assuming no climate change.

[2] Estimates for developing countries do not include China.

Effects of climate change with economic adjustment, but without farm-level adaptation

Changes in cereal production, cereal prices, and number of people at risk of hunger estimated for the GCM doubled CO_2 climate change scenarios (with direct CO_2 effects taken into account) are given in Table 14. These estimations are based upon dynamic simulations by the BLS in which the world food system was allowed to respond to climate-induced supply shortfalls of cereals and consequently higher commodity prices through increases in production factors (cultivated land, labor, and capital) and inputs such as fertilizer. The testing of climate change impacts without farm-level adaptation is unrealistic but was done for the purpose of establishing a baseline with which to compare the effects of farmer response.

Under the GISS scenario (which provides lower temperature increases) cereal production was estimated to decrease by just over 1 percent, while under the UKMO scenario (with the highest temperature increases) global production was estimated to decrease by more than 7 percent. The largest negative changes would occur in developing regions which average −9 percent to −11 percent, though the extent of decreased production would vary greatly by country depending on the projected climate. By contrast, production in developed countries was estimated to increase under all but the UKMO scenario (+11 percent to −3 percent). Thus, disparities in crop production between developed and developing countries were estimated to increase.

Price increases resulting from climate-induced decreases in yield were estimated to range between ~25 and 150 percent. In the case of the GISS scenario, the disequilibrium caused by the 5.3 percent reduction in yields of the unadjusted scenario would be resolved via market mechanisms in the adjusted case. This would result in a −1.2 percent consumer response and about a +4 percent (relative) producer response and would lead to 24 percent higher relative prices for cereals. Although this price response seems to be high, cereal prices account for only a modest fraction, perhaps 1/3 or less, of retail food prices. Hence, a 24 percent increase in world cereal prices does not imply a 24 percent increase in food prices.

These increases in price would likely affect the number of people with insufficient resources to purchase adequate amounts of food. The estimated number of hungry people increased approximately 1 percent for each 2–2.5 percent increase in prices (depending on climate change scenario). The number of people at risk of hunger increased by 10 percent to almost 60 percent in the climate change scenarios

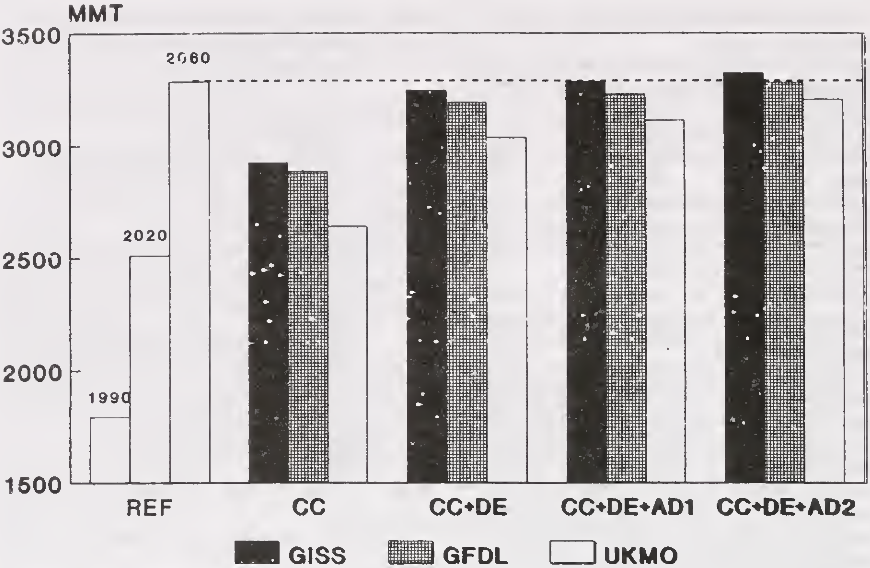

Figure 8 World cereal production projected by the BLS for the reference, GISS, GFDL, and UKMO doubled CO_2 climate change scenarios, with (CC + DE) and without (CC) direct CO_2 effects, and with Adaptation Levels 1 and 2 (AD1 and AD2). Adaptation Level 1 implies minor changes to existing agricultural systems; Adaptation Level 2 implies major changes.

tested, resulting in an estimated increase of between 60 and 350 million people in this condition (above the reference case of 640 million) by 2060.

Effects of climate change under different levels of farmer adaptation

Globally, both minor and major levels of adaptation were projected to help restore world production levels, when compared to the climate change scenarios with no adaptation (Figure 8). Growth in production under the reference scenario is far greater than average negative impacts of climate change. Averaged global cereal production would decrease by up to about 160 mmt (0 percent to − 5 percent) from the reference case of 3,286 mmt with Level 1 adaptations. These involved shifts in farm activities that are not very disruptive to regional agricultural systems. With adaptations implying major changes, global cereal production responses ranged from an additional 30 mmt, a slight increase, to a slight decrease of about 80 mmt (+ 1 percent to − 2.5 percent).

Level 1 adaptations would improve the comparative advantage of developed countries in world markets (Figure 9). In these regions cereal production was projected to increase by 4 percent to 14 percent over the reference case. However, the competitive positions of developing countries was estimated to benefit little from this level of adaptation. More extensive adaptation (Level 2) would virtually eliminate the global negative cereal yield impacts derived under the GISS and GFDL climate scenarios and would reduce impacts under the UKMO scenario to one third.

Figure 10 shows the estimated effects of climate change alone and of climate change with both levels of adaptation on cereal prices in 2060. As a consequence of climate change, world cereal prices were estimated to increase by about 25 percent to almost 150 percent. Under Adaptation Level 1, price increases range from 10 percent to 100 percent; under Adaptation Level 2, cereal price responses ranged from a decline of about 5 percent to an increase of 35 percent. When quantity of output declines, prices increase significantly. When quantity of output increases, prices drop.

As a consequence of climate change and Level 1 adaptations, the number of people at risk from hunger would increase by about 40 to 300 million (6 percent to 50 percent) from the reference case of 641 million (Figure 11). With more significant farmer adaptation (Level 2), the change in the

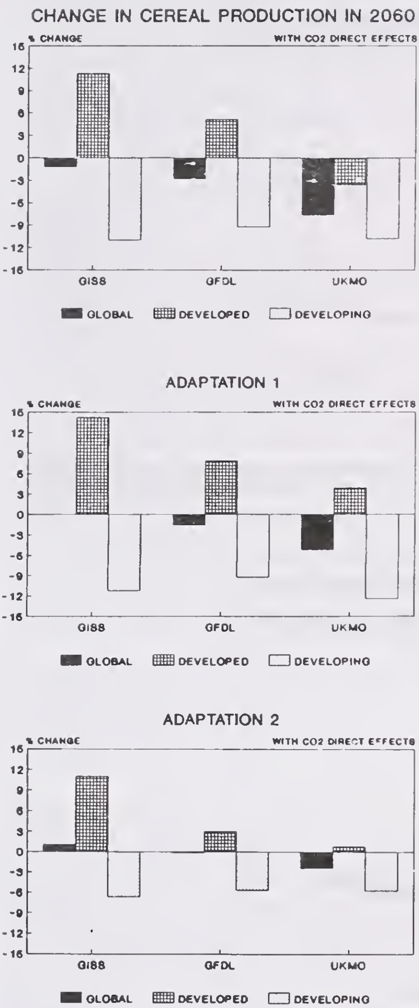

Figure 9 Change in world, aggregated developed country and developing country cereal production projected by the BLS under climate change scenarios in 2060 for no adaptation and Adaptation Levels 1 and 2. Reference scenario for 2060 assumed no climate change (global 3286 mmt, developed 1449 mmt, developing 1836 mmt).

number of people at risk from hunger ranged from −12 million for the GISS scenario to 120 million for the UKMO scenario (−2 percent and +20 percent). These results indicate that, except for the GISS scenario under Adaptation Level 2, the simulated farm-level adaptations did not entirely mitigate the negative effects of climate change on potential risk of hunger, even when economic adjustments, i.e., the production and price responses of the world food system, were taken into account.

Effects of climate change assuming full trade liberalization, lower economic growth rates, and lower population growth rates

For each of these alternate future assumptions, a new reference scenario was established with the BLS and then tested with the GCM climate change scenarios.

Full trade liberalization
Assuming full agricultural trade liberalization and no climate change by 2020 resulted in a projection of more efficient resource use. This led to a 3.2 percent higher value added in agriculture globally and 5.2 percent higher agricultural GDP in developing countries (excluding China) by 2060 compared to the original reference scenario. This policy change would result in almost 20 percent fewer people at risk of hunger. Global cereal production would increase by 70 mmt, with most of the production increases occurring in developing countries (Table 15).

Climate change impacts were then simulated under these new reference conditions. Under the same trade liberalization policies, global impacts due to climate change would be slightly reduced, with enhanced gains in production accruing to developed countries. Losses in production would be greater in developing countries. Price increases were reduced slightly from what would occur without full trade liberalization, and the number of people at risk of hunger was also reduced.

Reduced rate of economic growth
Estimates were also made of impacts under a lower economic growth scenario (10 percent lower than reference). These are indicated in Table 16. Lower economic growth results in a tighter supply situation, higher prices, and more people below the hunger threshold.

The effect of climate change on these trends is generally to reduce production, increase prices, and increase the number of people at risk from hunger. Developed countries increase cereal production in the GISS and GFDL scenarios even with the projected lower economic growth rates, but developing countries decrease production under all climate change scenarios

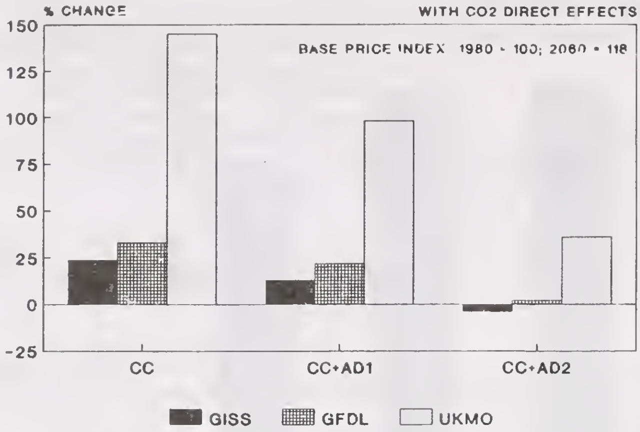

Figure 10 Change in cereal price index in 2060 calculated by the Basic Linked System under climate change scenarios for no adaptation and Adaptation Levels 1 and 2 (AD1 and AD2). Reference scenario for 2060 assumed no climate change (price index is 18 percent above 1980 levels).

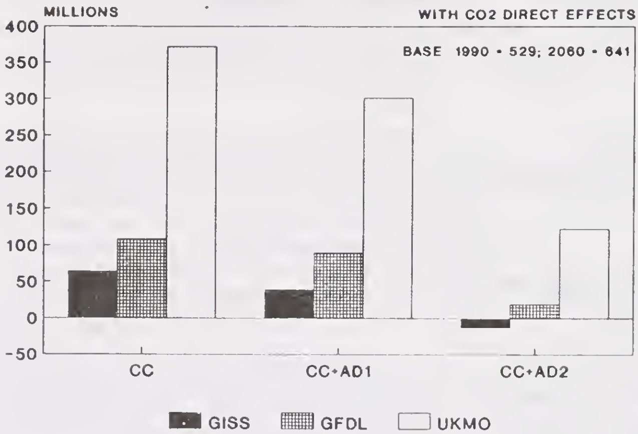

Figure 11 Change in number of people at risk of hunger in 2060 calculated by the Basic Linked System under climate change scenarios for no adaptation and Adaptation Levels 1 and 2 (AD1 and AD2). Reference scenario for 2060 assumes no climate change (529 million people are at risk of hunger in 1990; 641 million people are at risk of hunger in 2060).

Table 15. *Change in cereal production, price index, and the number of people at risk of hunger in 2060 assuming full trade liberalization and GCM climate change scenarios*

A. Cereal production (relative to Ref-FTL[1])

	Reference scenario[2] (mmt)	Ref-FTL (mmt)	GISS (mmt)	GFDL (mmt)	UKMO (mmt)
Global	3286	3356	−29	−87	−274
Developed	1449	1472	184	96	−55
Developing	1836	1884	−213	−183	−219

B. Change in cereal price index (% of Ref-FTL; 1970 = 100)

	Reference scenario	Ref-FTL	GISS	GFDL	UKMO
Cereal prices	121	153	19	30	135

C. Change in number of people at risk of hunger in 2060 (relative to Ref-FTL)

	Reference scenario (m)	Ref-FTL (m)	GISS (m)	GFDL (m)	UKMO (m)
Global[3]	641	532	53	98	378

Notes:
[1] Relative to Ref-FTL, reference scenario with full trade liberalization and no climate change.
[2] Reference scenario assumes no climate change.
[3] Entire increase in number of people at risk of hunger is in developing countries (excluding China).

Table 16. *Change in cereal production, price index, and the number of people at risk of hunger in 2060 assuming a low rate of economic growth and GCM climate change scenarios*

A. Cereal production (relative to Ref-E[1])

	Reference scenario[2] (mmt)	Ref-E (mmt)	GISS (mmt)	GFDL (mmt)	UKMO (mmt)
Global	3286	3212	−31	−87	−253
Developed	1449	1428	177	86	−51
Developing	1836	1786	−208	−173	−202

B. Change in cereal price index (% of Ref-E; 1970 = 100)

	Reference scenario	Ref-E	GISS	GFDL	UKMO
Cereal prices	121	137	21	30	139

C. Change in number of people at risk of hunger in 2060 (relative to Ref-E)

	Reference scenario (m)	Ref-E (m)	GISS (m)	GFDL (m)	UKMO (m)
Global[3]	641	757	63	119	412

Notes:
[1] Relative to Ref-E, reference scenario with a low rate of economic growth and no climate change.
[2] Reference scenario assumes no climate change.
[3] Entire increase in number of people at risk of hunger is in developing countries.

Altered rates of population growth

Lower population growth was shown to have a significant effect on cereal production, food prices, and number of hungry people (Table 17). Simulations based on rates of population growth according to UN low estimates resulted in a world population about 17 percent lower in year 2060 when compared to UN mid-estimates used in the reference run. The corresponding reduction in the developing countries (excluding China) would be about 19.5 percent, from 7.3 billion to 5.9 billion. The combination of higher GDP/capita (about 10 percent) and lower world population produced an estimated 40 percent fewer hungry people in the year 2060 compared to the reference scenario.

Even under the most adverse of the three climate scenarios (UKMO) the estimated number of hungry people was some 10 percent lower than the number estimated under the reference scenario without any climate change. Increases in world prices for agricultural products – in particular, cereals – under the climate change scenarios employing the low population projection were around 75 percent of those projected using the UN mid-estimate.

Figure 12 summarizes the generalized relative effects of different policies of trade liberalization, economic growth, and population growth on the production of cereals and people at risk of hunger. Alternative development assumptions made little difference with respect to the geopolitical patterns of the relative effects of climate change. In all cases, cereal production decreased, particularly in the developing world, while prices and population at risk from hunger increased due to climate change. The beneficial effects of trade liberalization and low population growth were of the same or an even greater (in the case of population) order of magnitude as the adverse effects of climate change. This suggests that there may be much to be gained from altering the conditions of trade and development as a strategy for addressing the climate change issue. The magnitude of

Table 17. *Changes in cereal production, price index, and the number of people at risk of hunger in 2060 assuming UN Low Estimate of Population growth and GCM climate change scenarios*

A. Cereal production (relative to Ref-P[1])

	Reference scenario[2] (mmt)	Ref-P (mmt)	GISS (mmt)	GFDL (mmt)	UKMO (mmt)
Global	3286	2929	−20	−76	−208
Developed	1449	1349	139	65	−52
Developing	1836	1582	−159	−141	−157

B. Change in cereal price index (% of Ref-P; 1970 = 100)

	Reference scenario	Ref-P	GISS	GFDL	UKMO
Cereal prices	121	92	19	28	116

C. Change in number of people at risk of hunger in 2060 (relative to Ref-P)

	Reference scenario (m)	Ref-P (m)	GISS (m)	GFDL (m)	UKMO (m)
Global[3]	641	395	18	50	183

Notes:

[1] Relative to Ref-P, reference scenario with UN Low Estimate of Population growth and no climate change.

[2] Reference scenario assumes no climate change.

[3] Entire increase in number of people at risk of hunger is in developing countries

adverse climate impacts was lowest, however, under the conditions of low population growth. An assumption of low population growth rate minimized the population at risk of hunger in both the presence and absence of climate change in the BLS simulations.

CONCLUSIONS

Climate change induced by increasing greenhouse gases is likely to affect crop yields differently from region to region across the globe. Under the climate change scenarios adopted in this study, the effects on crop yields in mid- and high-latitude regions appeared to be less adverse than those in low-latitude regions. However, the more favorable effects on yield in temperate regions depended to a large extent on full realization of the potentially beneficial direct effects of CO_2 on crop growth. Decreases in potential crop yields are likely to be caused by shortening of the crop growing period, decrease in water availability due to higher rates of evapotranspiration, and poor vernalization of temperate cereal crops. When adaptations at the farm level were tested (e.g., change in planting date, switch of crop variety, changes in fertilizer application and irrigation), compensation for the detrimental effects of climate change was found to be more successful in developed countries.

When the economic implications of these changes in crop yields were explored in a world food trade model, the relative ability of the world food system to absorb impacts decreased with the magnitude of the impact. Regional differences in effects remained noticeable, and developed countries are expected to be less affected by climate change than developing economies. Dynamic economic adjustments can compensate for lower impact scenarios, such as the GISS and GFDL climate scenarios, but not higher impact ones, such as the UKMO scenario. Prices of agricultural products were found to be related to the magnitude of the climate change impact, and incidence of food poverty increased in all but one of the climate change scenarios tested.

When the effects of lower future population, lower economic growth rates, and partial trade liberalization were tested in the food trade model, reduced population growth rates were projected to have the largest effect on minimizing the impact of climate change. Lower economic growth resulted in tighter food supplies, and consequently resulted in higher rates of food poverty. Full trade liberalization in agriculture provided for more efficient resource use and reduced the number of people at risk of hunger by about 100 million (from the reference case of about 640 million in 2060). However, all of the scenarios of future climate adopted in this part of the study exacerbated estimates of the number of people at risk of hunger.

It should be emphasized that the results reported here are not a forecast of the future. There are very large uncertainties that preclude making forecasts, particularly the lack of information on possible climate change at the regional level, on the effects of technological change on agricultural productivity, on trends in demand (including population growth), and on the wide array of possible adaptations. The adoption of efficient adaptation techniques is far from certain. In developing countries, there may be social or technical constraints, and adaptive measures may not necessarily result in sustainable production over long time-frames. The availability of water supplies for irrigation and the costs of adaptation are both critical needs for further research.

Future trace gas emission rates, as well as when the full magnitude of their effects will be realized, are not certain, and only a limited range of GCM climate change scenarios, representing the upper end of the projected warming, was tested. However, it can be argued that the use of scenarios from the higher GCM projections provides perspective on

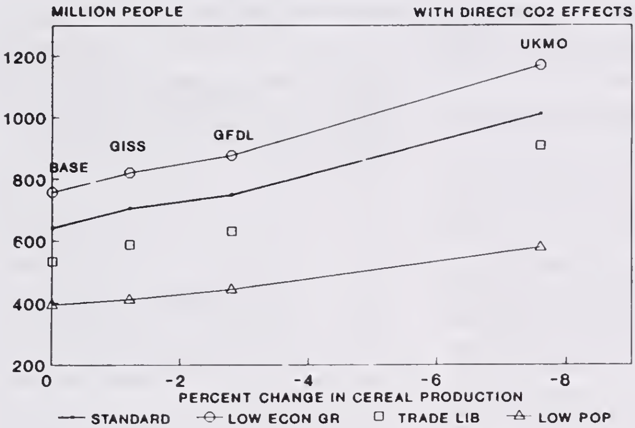

Figure 12 Effects of different assumptions and policies on number of people at risk from hunger calculated by the Basic Linked System under the climate change scenarios.

the downside risk of global warming projections. Because of these uncertainties, the study should be considered as an exploratory assessment of the sensitivity of the world food system to a limited number of what is, in effect, a much wider array of possible futures.

Determining how countries, particularly developing countries, can and will respond to reduced yields and increased costs of food is a critical research need arising from this study. Will such countries be able to import large amounts of food? From a political and social standpoint, these results show a decrease in food security in developing countries. The study suggests that the worst situation arises from a scenario of severe climate change, low economic growth, and little farm-level adaptation. In order to minimize possible adverse consequences – production losses, food price increases, and more people at risk of hunger – the way forward is to encourage the agricultural sector to continue to develop crop breeding and management programs for heat and drought conditions (measures that will be useful even today in improving productivity in marginal environments) and to encourage the nations of the world to take measures to slow population growth. The latter step would also be consistent with efforts to slow emissions of greenhouse gases, the source of the problem, and thus the rate and eventual magnitude of global climate change.

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University of Florida
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University of Georgia
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National Center for Atmospheric Research
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O. E. Sala and J. M. Paruelo. Implications of Climate Change for International Agriculture: Global Food Production, Trade, and Vulnerable Regions: The Argentinean Case.

Australia
B. D. Baer, W. S. Meyer, and D. Erskine. Global Climate Change: Possible Effects on Australian Agriculture.

Bangladesh
Z. Karim, M. Ahmed, S. G. Hussain, and Kh. B. Rashid. Impact of Climate Change on the Production of Modern Rice in Bangladesh.

Brazil
O. J. F. de Siqueira, J. R. B. Farias, and L. M. A. Sans. Potential Effects of Global Climate Change for Brazilian

Agriculture: Simulation Studies Applied for Wheat, Maize, and Soybean.

Canada
M. Brklacich, R. Stewart, V. Kirkwood, and R. Muma. Effects of Global Climatic Change on Wheat Yields in the Canadian Prairie: Summary Report.

China
Z. Jin, D. Ge, H. Chen, J. Fang, and X. Zheng. Effects of Climate Change on Rice Production and Strategies for Adaptation in Southern China.

Egypt
H. M. Eid. Climate Change and Crop Modeling Study in Egypt.

France
R. Delécolle, D. Ripoche, F. Ruget, and G. Gosse. Possible Effects of Increasing CO_2 Concentration on Wheat and Maize Crops in North and Southeast France.

India
D. G. Rao. Impact of Climate Change on Simulated Wheat Production in India.

Japan
H. Seino. Indications of Climate Change for Japanese Crop Production.

Mexico
D. Liverman, M. Dilley, K. O'Brien, and L. Menchaca. The Impacts of Climate Change on Maize in Mexico.

Pakistan
A. Qureshi and A. Iglesias. Effects of Climate Change on Simulated Wheat Production in Pakistan.

Philippines
C. R. Escaño and L. Buendia. Climate Impact Assessment for Agriculture in the Philippines.

Thailand
M. L. C. Tongyai. Effects of Climate Change on Thai Agriculture.

Russia
G. Menzhulin, L. Koval, and A. Badenko. Potential Effects of Global Warming and Atmospheric Carbon Dioxide on Wheat Production in the Commonwealth of Independent States.

USA
C. Rosenzweig, B. Curry, T. Y. Chou, J. Ritchie, J. Jones, and R. Peart. Simulated Wheat, Corn, and Soybean Response to Predicted Climate Change in the US.

Uruguay
W. E. Baethgen. Climate Change and Crop Modeling Study in Uruguay.

Zimbabwe
P. Muchena. Implications of Climate Change for International Agriculture: Global Food Production, Trade, and Vulnerable Regions.

APPENDIX 3. COUNTRIES IN BASIC LINKED SYSTEM REGIONAL GROUPS

EC
Belgium, Denmark, France, Federal Republic of Germany (pre-unification), Italy, Ireland, Luxembourg, Netherlands, and United Kingdom

Eastern Europe and former USSR
Bulgaria, former Czechoslovakia, former Democratic Republic of Germany, Hungary, Poland, Romania, and former USSR

Africa
Oil exporters
Algeria, Angola, Congo, Gabon
Medium-income/caloric exporters
Ghana, Ivory Coast, Senegal, Cameroon, Mauritius, Zimbabwe
Medium-income/caloric importers
Morocco, Tunisia, Liberia, Mauritania, Zambia
Low-income/caloric exporters
Benin, Gambia, Togo, Ethiopia, Malawi, Mozambique, Uganda, Sudan
Low-income/calorie importers
Guinea, Mali, Niger, Sierra Leone, Upper Volta, Central African Republic, Chad, Zaire, Burundi, Madagascar, Rwanda, Somalia, Tanzania

Latin America
High-income/caloric exporters
Costa Rica, Panama, Cuba, Dominican Republic, Ecuador, Surinam, Uruguay
High-income/caloric importers
Jamaica, Trinidad and Tobago, Chile, Peru, Venezuela
Medium to low income
El Salvador, Guatemala, Honduras, Nicaragua, Columbia, Guyana, Paraguay, Haiti, Bolivia

Far East Asia
High to medium income/caloric exporters
Malaysia, Philippines
High to medium income/caloric importers
Republic of Korea, Laos, Vietnam, Korea DPR, Cambodia
Low income
Burma, Sri Lanka, Bangladesh
Oil exporters/high income
Libya, Iran, Iraq, Saudi Arabia, Cyprus, Lebanon, Syria

Near East Asia
Medium to low income
Yemen, Afghanistan

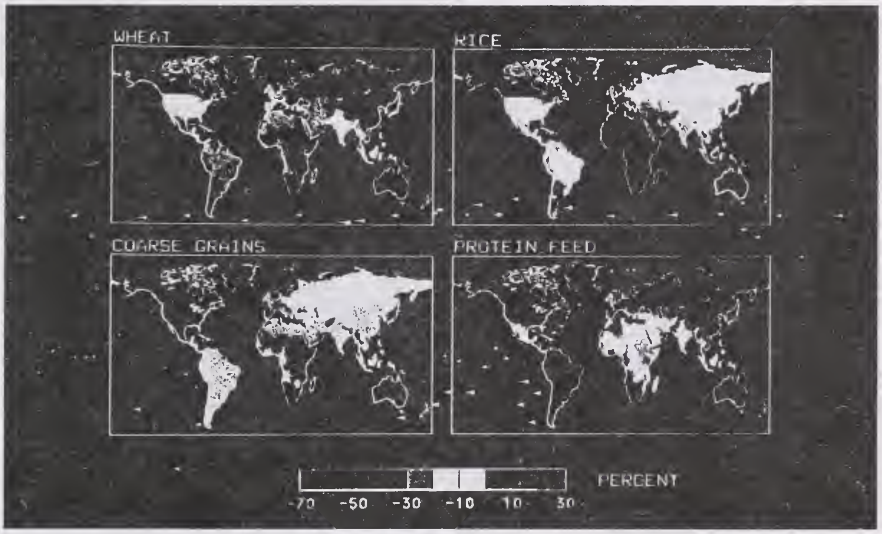


Plate 1 Estimated change in average wheat, rice, coarse grains, and protein feed yield for the GFDL climate change scenario with direct CO_2 effects. Results shown are averages for countries and groups of countries in the BLS world food trade model; regional variations within countries are not reflected.

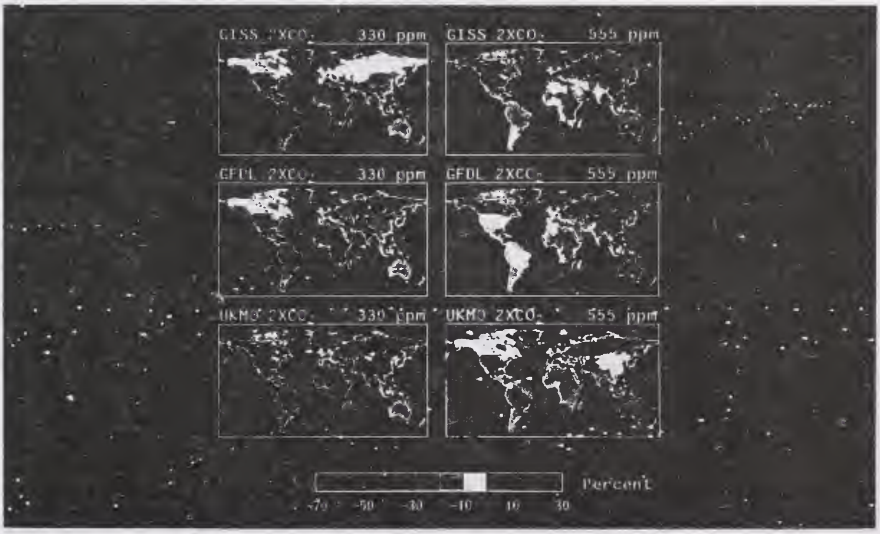


Plate 2 Estimated change in average national grain yield (wheat, rice, coarse grains, and protein feed) for the GISS, GFDL, and UKMO climate change scenarios. The left-hand column shows effects of climate change alone (330 ppm CO_2); the right-hand column shows the combined effects of climate change and direct CO_2 effects (555 ppm CO_2)

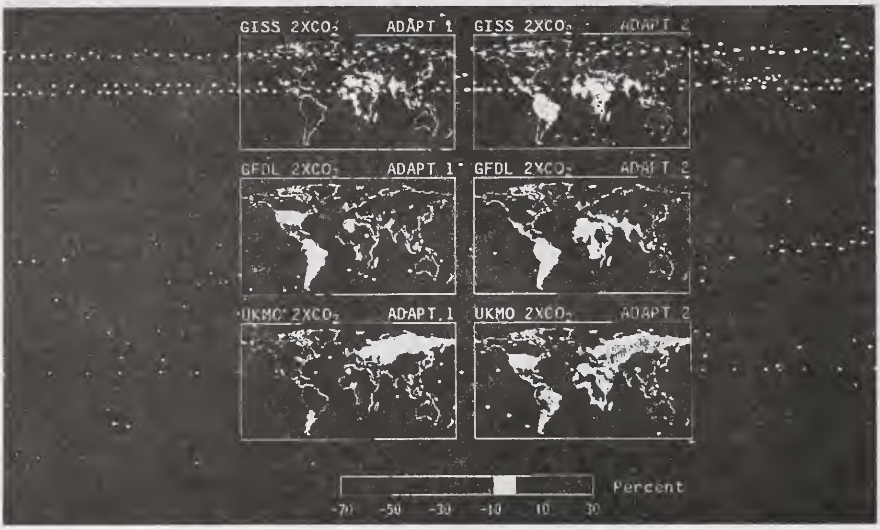


Plate 3 Estimated change in average national grain yield (wheat, rice, coarse grains, and protein feed with direct 555 ppm CO_2 effects) under two levels of adaptation for the GISS, GFDL, and UKMO climate change scenarios. Adaptation Level 1 signifies minor changes to existing agricultural systems; Adaptation Level 2 signifies major changes. Results shown are averages for countries and groups of countries in the BLS world food trade model; regional variations within countries are not reflected. (Rosenzweig and Parry, 1994).

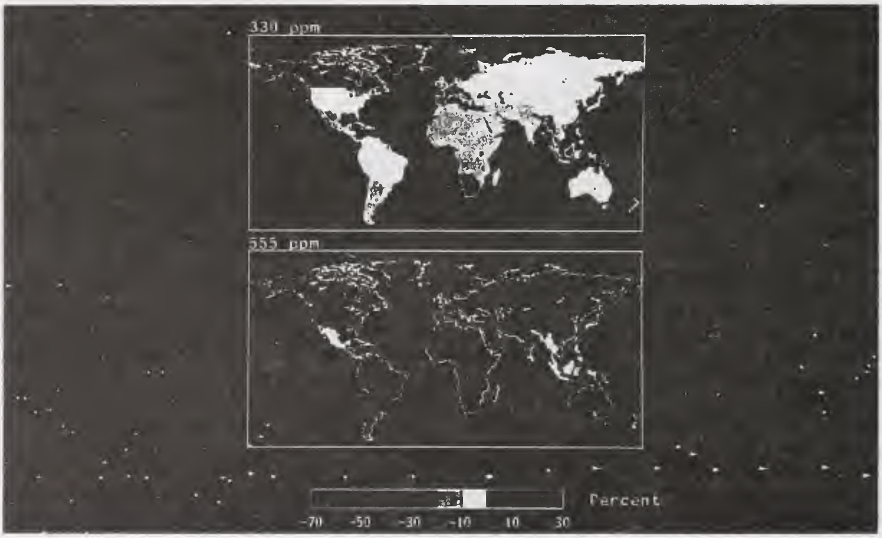


Plate 4 Estimated change in average national grain yield (wheat, rice, coarse grains, and protein feed) for the GISS-A (GISS 2030s) climate change scenario. The upper map shows effects of climate change alone (330 ppm CO_2); the lower map shows the combined effects of climate change and direct CO_2 effects (555 ppm CO_2) Results shown are averages for countries and groups of countries in the BLS world food trade model; regional variations within countries are not reflected.

Plate 5 An example of an undeveloped buffer of land adjacent to the coast in Uruguay, Parque del Plata, Department of Canelones. In this case the buffer is about 100 meters wide, preserving the natural sand dunes which provide protection against storms. The undeveloped land also allows some erosion to occur in the future with little or no adverse impacts for the adjacent properties. (Photograph by C.R. Volonté)

Plate 6 Erosion is already causing adverse impacts in Venezuela and many homes have had to be abandoned south of Boca de Aroa, State of Falcon. (Photograph by C.R. Volonté)

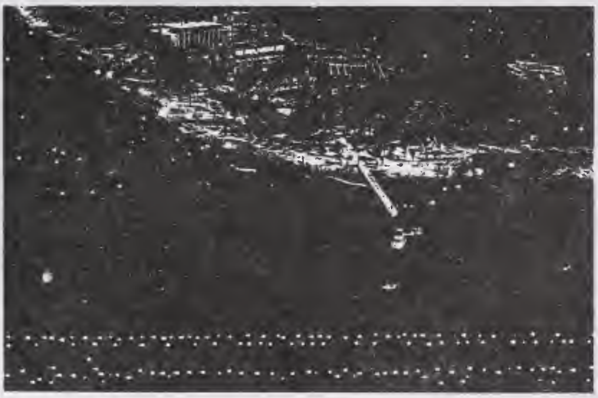


Plate 7 A typical tourist resort south of Dakar in Senegal. These facilities are particularly vulnerable to erosion as they were often built very close to the water's edge. (Photograph by K.C. Dennis)

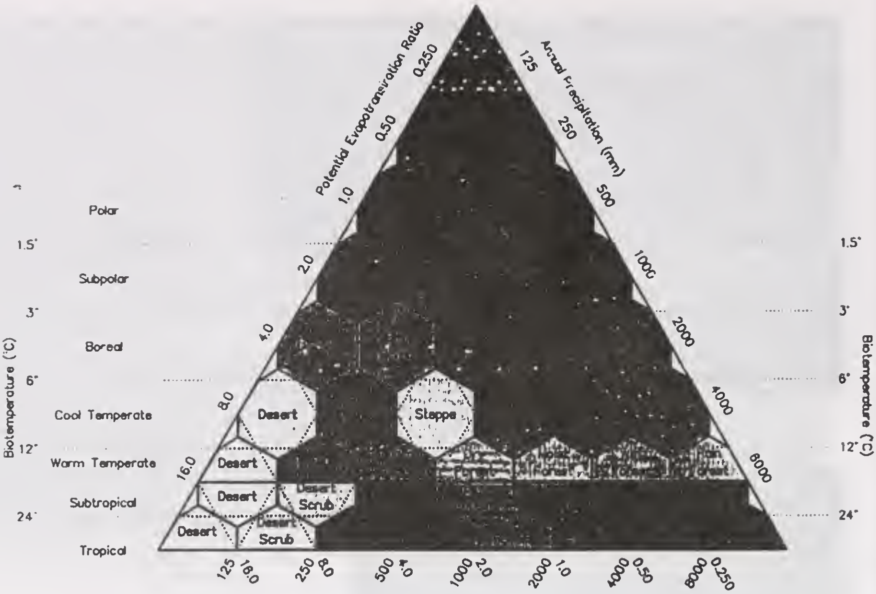
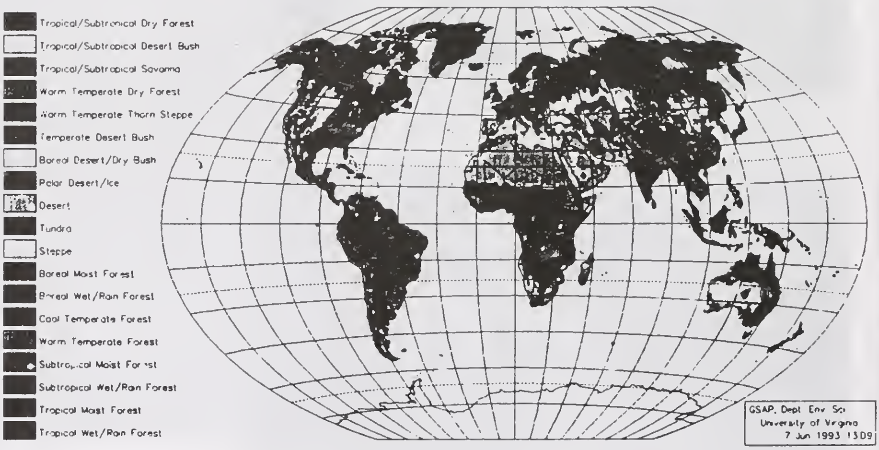


Plate 8 Holdridge climate–vegetation classification scheme (from Holdridge 1967).



9a

Plate 9a–e Global map of Holdridge Life Zones under (a) current climate conditions, and the climate change scenarios based on (b) GFDL, (c) GISS, (d) OSU, and (e) UKMO General Circulation Models (see Chapter 1). The resolution is 0.5° latitude × 0.5° longitude. Key relating aggregated classes to life zone is shown in Plate 8.


Tropical/Subtropical Dry Forest
Tropical/Subtropical Desert Bush
Tropical/Subtropical Savanna
Warm Temperate Dry Forest
Warm Temperate Thorn Steppe
Temperate Desert Bush
Boreal Desert/Dry Bush
Polar Desert/Ice
Desert
Tundra
Steppe
Boreal Moist Forest
Boreal Wet/Rain Forest
Cool Temperate Forest
Warm Temperate Forest
Subtropical Moist Forest
Subtropical Wet/Rain Forest
Tropical Moist Forest
Tropical Wet/Rain Forest
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University of Virginia
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9b


Tropical/Subtropical Dry Forest
Tropical/Subtropical Desert Bush
Tropical/Subtropical Savanna
Warm Temperate Dry Forest
Warm Temperate Thorn Steppe
Temperate Desert Bush
Boreal Desert/Dry Bush
Polar Desert/Ice
Desert
Tundra
Steppe
Boreal Moist Forest
Boreal Wet/Rain Forest
Cool Temperate Forest
Warm Temperate Forest
Subtropical Moist Forest
Subtropical Wet/Rain Forest
Tropical Moist Forest
Tropical Wet/Rain Forest
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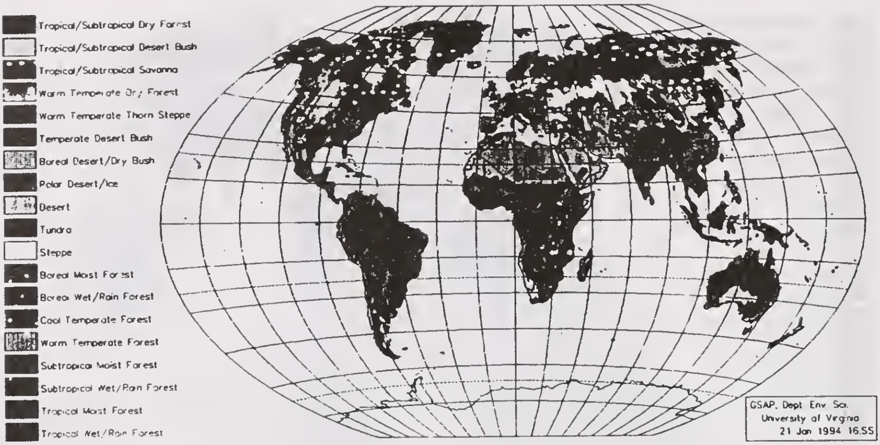
9c


Tropical/Subtropical Dry Forest
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Cool Temperate Forest
Warm Temperate Forest
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Subtropical Wet/Rain Forest
Tropical Moist Forest
Tropical Wet/Rain Forest
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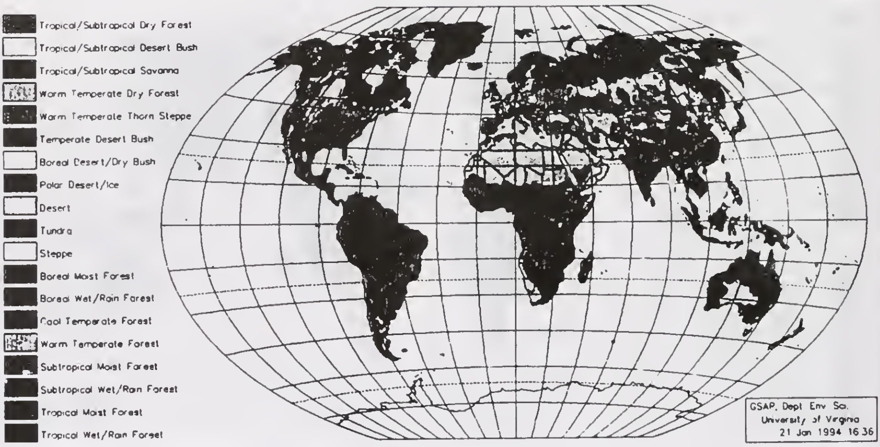
9d


Tropical/Subtropical Dry Forest
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Cool Temperate Forest
Warm Temperate Forest
Subtropical Moist Forest
Subtropical Wet/Rain Forest
Tropical Moist Forest
Tropical Wet/Rain Forest
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9e

Plate 10a–c Eco-climatic zones of Costa Rica: (a) current climate; (b) under a +2.5°C, +10 percent precipitation scenario; and (c) under a +3.6°C, +10 percent precipitation scenario.

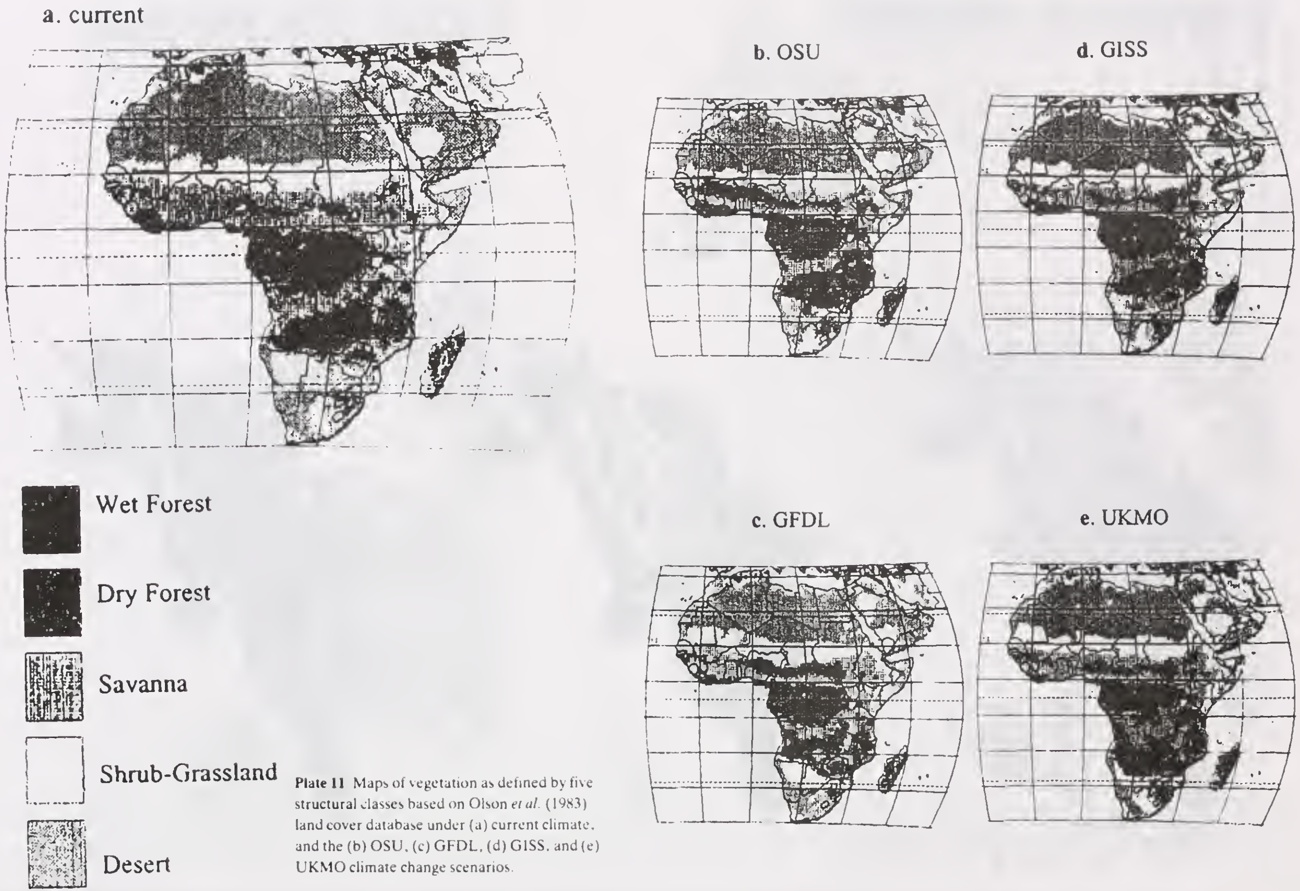

Plate 11 Maps of vegetation as defined by five structural classes based on Olson *et al.* (1983) land cover database under (a) current climate, and the (b) OSU, (c) GFDL, (d) GISS, and (e) UKMO climate change scenarios.

As Climate Changes:
International Impacts and Implications

Kenneth M. Strzepek and Joel B. Smith, Editors

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13

Agriculture in a Changing Climate: Impacts and Adaptation

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CONTENTS

EXECUTIVE SUMMARY

Substantial research progress has been made on the impacts of climate change on agriculture since the 1990 IPCC assessment, with new studies for different sites and countries covering many areas of the world. New studies also have been conducted that integrate site, country, and regional impacts to provide information about how global agricultural production and consumption may be affected. On the whole, these studies support the evidence presented in the first IPCC assessment that global agricultural production can be maintained relative to baseline production in the face of climate changes likely to occur over the next century (i.e., in the range of 1 to 4.5°C) but that regional effects will vary widely. Major uncertainties result from the lack of reliable geographic resolution in future climate predictions, difficulties in integrating and scaling-up basic physiologic responses and relationships, and difficulty in estimating farm sector response and adaptation to changing climate as it varies across the world. Thus, while there will be winners and losers stemming from climate impacts on agricultural production, it is not possible to distinguish reliably and precisely those areas that will benefit and those that will lose.

Major conclusions of the assessment cover four areas: (1) The direct and indirect effects of changes in climate and atmospheric constituents on crop yield, soils, agricultural pests, and livestock; (2) estimates of yield and production changes for specific localities, countries, and the world, based on studies that integrate multiple direct and indirect effects; (3) the conditions that determine vulnerability and areas and populations that are relatively more vulnerable to adverse changes; and (4) adaptation potential.

Direct and Indirect Effects

Experimental results, detailed modeling of basic processes, and knowledge of physical and biological processes provide basic understanding of direct and indirect effects of climate on agricultural production:

- The results of a large number of experiments to resolve the effect of elevated CO_2 concentrations on crops have confirmed a beneficial effect. The mean value yield response of C_3 crops (most crops except maize, sugar cane, millet, and sorghum) to doubled CO_2 is +30%. Measured response ranges from -10% to +80%. Only gradually is the basis for these differences being resolved. Factors known to affect the response include the availability of plant nutrients, the crop species, temperature, precipitation, and other environmental factors. Differences in experimental technique also are responsible for variations in the measured response (High Confidence).
- Changes in soils, e.g., loss of soil organic matter, leaching of soil nutrients, and salinization and erosion, are a likely consequence of climate change for some soils in some climatic zones. Cropping practices such as crop rotation, conservation tillage, and improved nutrient management are, technically, quite effective in combating or reversing deleterious effects (High Confidence).
- Livestock production will be affected by changes in grain prices, changes in the prevalence and distribution of livestock pests, and changes in grazing and pasture productivity. Analyses indicate that intensively managed livestock systems have more potential for adaptation than crop systems. In contrast, adaptation may be more problematic in pastoral systems where production is very sensitive to climate change, technology changes introduce new risks, and the rate of technology adoption is slow (see Chapter 2) (Medium Confidence).
- The risk of losses due to weeds, insects, and diseases is likely to increase (Low Confidence).

Regional and Global Production Effects

To evaluate the direct and indirect effects of climate on yield at the farm, regional, or higher levels requires integrated models that consider system interactions. Issues of scale add uncertainty, and higher-order models have not generally taken into account the climatic effects on soils and pests. Despite these limitations, climate change studies show:

- Crop yields and productivity changes will vary considerably across regions. Thus, the pattern of agricultural production is likely to change in a number of regions (High Confidence).
- Global agricultural production can be maintained relative to base production under climate change as expressed by general circulation models (GCMs) under doubled CO_2 equilibrium climate scenarios (Medium Confidence).
- Based on global agricultural studies using doubled CO_2 equilibrium GCM scenarios, lower-latitude and lower-income countries have been shown to be more negatively affected. Again, crop model simulation results vary widely, e.g., ±20% changes in yield, for specific countries and sites across studies and GCM scenarios (Medium Confidence).

Vulnerability

Vulnerability is used here to mean the *potential* for negative consequences given the range of possible climate changes that might reasonably occur and is not a prediction that negative consequences will occur. Vulnerability can be defined at different scales, including yield, farm or farm sector, regional economic, or hunger vulnerability.

- Vulnerability to climate change depends on physical and biological response but also on socioeconomic characteristics. Low-income populations depending on isolated agricultural systems, particularly dryland systems in semi-arid and arid regions, are particularly vulnerable to hunger and severe hardship. Many of these at-risk populations are found in Sub-Saharan Africa, South and Southeast Asia, as well as some Pacific Island countries and tropical Latin America (High Confidence).

Adaptation

Uncertainty remains with regard to the ability of agricultural systems to adapt to climate change. Historically, farming systems have responded to a growing population and have adapted to changing economic conditions, technology, and resource availabilities. It is uncertain whether the rate of change of climate and required adaptation would add significantly to the disruption likely due to future changes in economic conditions, population, technology, and resource availabilities.

- Adaptation to climate change is likely; the extent depends on the affordability of adaptive measures, access to technology, and biophysical constraints such as water resource availability, soil characteristics, genetic diversity for crop breeding, and topography. Many current agricultural and resource policies are likely to discourage effective adaptation and are a source of current land degradation and resource misuse (High Confidence).
- National studies have shown incremental additional costs of agricultural production under climate change which could create a serious burden for some developing countries (Medium Confidence).

13.1. Introduction

Climate change will affect agriculture through effects on crops (Section 13.2); soils (Section 13.3); insects, weeds, and diseases (Section 13.4); and livestock (Section 13.5). Climatic conditions interact with agriculture through numerous and diverse mechanisms. Mechanisms, effects, and responses include, for example, eutrophication and acidification of soils, the survival and distribution of pest populations, the effects of CO_2 concentration on tissue- and organ-specific photosynthate allocation, crop breeding aims, animal shelter requirements, and the location of production (Brunnert and Dämmgen, 1994). Variation of agricultural and climatic conditions across the world leads to different local and regional impacts (Section 13.6). High levels of uncertainty necessitate assessment of vulnerability to the adverse effects of potential climate change (Section 13.7). The effects of climate change on local, national, and regional economies and food supplies depend on future economic and agricultural conditions and on the international transmission of supply shocks through international trade (Section 13.8). Historically, agriculture has proved to be highly adaptive to changing conditions, but uncertainty remains with regard to adaptation to potential climate change (Section 13.9). Emission-control efforts also will likely affect agriculture (Chapter 23), as will competition for land and water resources from other sectors affected by climate change (Chapter 25).

13.2. Climatic Effects on Crop Plants

The main climate variables important for crop plants, as for other plants, are temperature, solar radiation, water, and atmospheric CO_2 concentration. Important differences in temperature sensitivity and response to CO_2 exist among C_3, C_4, and CAM plants (Chapter A). While the basic physiological response of crop plants are no different than other plants of similar types, crop plants have been selected for particular traits and grow under more highly controlled conditions than plants growing in forests (managed and unmanaged) or other ecosystems. Most crop plants are C_3, the principal C_4 exceptions are maize, millet, sorghum, and sugar cane. Crop traits are selected and bred into different varieties to produce high yields for different climate and resource conditions. Most crop plants are grown as annuals (e.g., grains, potatoes, and most vegetable and fiber crops) with the crop species, variety, and planting time chosen by the farmer at the start of each growing season. Tree fruits, coffee, tea, cocoa, bananas, grapes, many forage and pasture crops, and other small fruits are the principal perennials. Nutrients and water which may be limited under natural conditions are more likely to be (or can be) augmented via fertilization, irrigation, and management of crop residue. Competition with other plants is controlled. The primary focus of crop production is the efficient production of harvestable yield, usually of only one component of the plant (e.g., seed, fruit, root, leaf).

13.2.1. Elevated CO_2 and Crops

Experiments concerning crop performance at elevated CO_2 concentrations in general show a positive but variable increase in productivity for annual crops (Kimball, 1983; Strain and Cure, 1985; Cure and Acock, 1986; Allen *et al.*, 1990; Kimball *et al.*, 1990; Lawlor and Mitchell, 1991; Bazzaz and Fajer, 1992; Gifford and Morison, 1993; Koerner, 1993; Rozema *et al.*, 1993; Mooney and Koch, 1994; Rogers *et al.*, 1994). Annual C_3 plants exhibit an increased production averaging about 30% at doubled (700 ppm) CO_2 concentrations; both biomass and seed production show an increase in almost all experiments under controlled conditions (Cure and Acock, 1986; Rogers and Dahlmann, 1993). Although the mean value response (+30% for C_3 crops) has been confirmed, variations in responsiveness between plant species and ecosystems persist (from -10% to +80%), and only gradually is the basis for these differences being resolved. Fewer experiments have been conducted with perennial crops—woody species in particular—but evidence suggests that the growth response would be less than for annual crops; the measured response for C_4 crops is much smaller than that for C_3 crops.

Variations in the growth enhancement among crops and different varieties of the same crop and over years are high, and interactions with nutrient and water availability are complex (e.g., Goudriaan and De Ruiter, 1983; Chaudhuri *et al.*, 1986; Mitchell *et al.*, 1993). The extent and occurrence of physiological adaptations of the photosynthetic apparatus, particularly of perennial plants, to long-term exposure to high CO_2 concentrations—which is more directly relevant to long-term climate change—are still unresolved (Cure and Acock, 1986; Bazzaz and Fajer, 1992; Wolfe and Erickson, 1993). Plants with nitrogen-fixing symbionts (e.g., peas, beans, alfalfa), under favorable environmental conditions for both symbiont and plant, tend to benefit more from enhanced CO_2 supplies than do other plants (Cure *et al.*, 1988). The content of nonstructural carbohydrates generally increases under high CO_2, while the concentrations of mineral nutrients and proteins are reduced (Mooney and Koch, 1994; Rogers *et al.*, 1994; Koerner and Miglietta, in press). Root/shoot ratios often increase under elevated CO_2 levels favoring root crops and also contribute to soil organic matter build-up (Mauney *et al.*, 1992; Mitchell *et al.*, 1993). Crop plants, like other plants, show increased water use efficiency under elevated CO_2 levels, but water consumption on a ground-area basis vs. a leaf-area basis is much less affected. Water use on a ground-area basis can actually increase if leaf area (canopy) increases. The range of water-use efficiencies among varieties for major crops is wide (e.g., Cure and Acock, 1986; Kimball *et al.*, 1993; Sombroek and Gommes, 1993), providing the opportunity to breed or select for improved efficiency. At higher CO_2 levels, plant growth damage done by air pollutants like nitrogen oxide (NO_x), sulfur dioxide (SO_2), and ozone (O_3) is reduced because of partial stomatal closing and other physiological changes (Van de Geijn *et al.*, 1993).

The wide range in estimated responses to elevated CO_2 is due in large part to the different experimental systems employed

(Gifford and Morison, 1993), each with advantages and disadvantages (Krupa and Kickert, 1989). Year-to-year variations in response also occur because of varying weather conditions that more or less favor CO_2 response of crops. The most widely used experimental system is the open-top chamber. Free-air CO_2 enrichment (FACE) experiments are more expensive but attempt to create conditions close to those likely to be experienced in an open field. Initial results from these experiments confirm the basic positive response of crops to elevated CO_2, but studies have been conducted only for a few crops (Mauney *et al.*, 1992). In addition, even the FACE experimental set-up creates a modified area (Kimball *et al.*, 1993; Vugts, 1993) analogous to a single irrigated field within a dry environment.

13.2.2. Temperature, Moisture, and Other Variables

Plant growth and crop yields clearly depend on temperature and temperature extremes, as shown for five major food crops (Table 13-1), and vary for crops with different photosynthetic pathways (Le Houerou *et al.*, 1993). The optimum range for C_3 crops is 15 to 20°C and for C_4 crops 25 to 30°C; for CAM crops a nighttime temperature of 10 to 20°C is optimal. C_4 and CAM crops require a minimum temperature of 10 to 15°C for growth and are relatively sensitive to frost. The minimum temperature for C_3 crops ranges from 5 to 10°C; C_3 crops exhibit variable frost sensitivity. Cumulative temperature above minimum growing temperature is an important determinant of crop phenological development. For annual crops, warmer temperatures speed development, shortening the period of growth and lowering yield if shortened growth period is not fully compensated by more rapid development at the higher temperature (Ellis *et al.*, 1990). The amount of light received during the reproductive stage may determine whether yields fall (Acock and Acock, 1993).

***Table 13-1:** Crop physiology: Temperature thresholds (°C) of some major crops of the world (optimum range refers to the entire growing season and narrows under high light and elevated CO_2).*

Crop	Optimum Range	Lower Range	Upper Range	References/ Remarks
Wheat (C_3)	17–23	0	30–35	Burke *et al.*, 1988; Behl *et al.*, 1993; optimal enzyme function and representative seasonal foliage temperature
Rice (C_3)	25–30	7–12	35–38	Le Houerou *et al.*, 1993; Yoshida,1981
Maize (C_4)	25–30	8–13	32–37	Le Houerou, 1993; Decker *et al.*, 1986; Pollak and Corbett, 1993; Ellis *et al.*, 1992; Long *et al.*, 1983
Potato (C_3)	15–20	5–10	25	Haverkort, 1990; Prange *et al.*, 1990
Soybean (C_3)	15–20	0	35	Hofstra and Hesketh, 1969; Jeffers and Shibles, 1969

The variation of temperature requirements and temperature extremes for different cultivars of the same species and among species, however, is quite wide for most crops, as shown for major crops such as wheat, rice, maize, and soybean (Table 13-2). Such variation in requirements provides significant scope for adaptation through switching among existing cultivars and crops or introducing genetic variability through conventional plant breeding.

It has been suggested that higher mean temperatures will be accompanied by higher variability and more frequent occurrence of extremes (Katz and Brown, 1992). Such changes could severely affect plant functioning at low and high mean temperatures (Larcher, 1980; Kuiper, 1993).

Climate variability and resultant interannual variability in yield is a fundamental feature of most cropping systems (Gommes, 1993). In temperate areas, low temperatures and/or frost occurrences are the usual limiting factor for growing season length. In tropical and subtropical areas, where temperature variation is less extreme throughout the year than in temperate areas, season-length and seasonal variation depend on regular patterns of precipitation.

Temperature, solar radiation, relative humidity, wind, and precipitation vary not only over the season and year but on a daily basis. The effects of variability can be both positive and negative depending on the crop and the nature of the variability. Cool-season vegetable crops (e.g., spinach, cauliflower, broccoli) perform best when nights are cool; their quality deteriorates under warmer temperatures. Apples, pears, cherries, and many other tree fruits require winter chilling periods for buds to set but can suffer near-total loss of the fruit crop if late frosts damage the blossoms. Alternate thawing and freezing of the ground can cause the loss of perennial forage crops such as alfalfa. Extreme climatic events (e.g., storms with high winds, flooding, heavy rains, hail, hard late or early frosts) can be responsible for severe or total crop loss.

The anticipated increase in temperatures with global warming can lead to spikelet sterility in rice, loss of pollen viability in maize, reversal of vernalization in wheat, and reduced formation of tubers and tuber bulking in potatoes for areas near critical thresholds (Table 13-3). Yield losses can be severe in these

Table 13-2: Crop phenology for important crops.

Crop	Base Temp. (°C)	Max. Devel. (°C)	Emergence to Pre-Anthesis (degree days)	Post-Anthesis to Maturity (degree days)	Reference
Wheat	0	20–25	750–1300	450–1050	Van Keulen and Seligman, 1987; Elings, 1992; Hodges and Ritchie, 1991
Rice	8	25–31	700–1300	450–850	Yoshida, 1981; Penning de Vries, 1993; Penning de Vries *et al.*, 1989
Maize	7	25–35	900–1300	700–1100	Van Heemst, 1988; Pollak and Corbett, 1993; Kiniry and Bonhomme, 1991; Rötter, 1993
Soybean	0	25–35	highly variable	450–750	Wilkerson *et al.*, 1989; Swank *et al.*, 1987

Source: Adapted from Acock and Acock, 1993.
Notes: Base Temp. = minimum temperature for growth; Max. Devel. = optimum temperature for crop development; Emergence to Pre-Anthesis = cumulative degree days needed from crop emergence to pre-anthesis (flowering); Post-Anthesis to Maturity = cumulative degree days required (after flowering) to reach maturity.

cases, if temperatures exceed critical limits for periods as short as 1 hour during anthesis (flowering). Burke *et al.* (1988) found that under ample water supply different crop species manage to maintain foliage temperature within their specific optimum range (thermal kinetic window), thereby maximizing biomass accumulation.

Species-specific optimal temperature ranges are relatively narrow compared to diurnal and seasonal foliage temperature fluctuations. If temperature variability on a daily and seasonal basis were to decrease, crop cultivars in environments with mean temperatures close to cultivar-specific optima could profit from prolonged exposure to optimum temperatures. While variability in some climatic dimensions may increase, the temperature increase since the 1940s has been due mainly to increased nighttime temperature (Kukla and Karl, 1993), thus reducing the diurnal variation of temperature and considerably influencing the nighttime respiration. The response of respiration is theoretically derived and experimentally well-established, but the concept is challenged for situations where plants or crops are grown continuously and have adapted to the higher temperature (Gifford and Morison, 1993).

Table 13-3. Temperature thresholds: High temperature effects on key development stages of five major arable crops.

Crop	Effect	Reference
Wheat	Temperature >30°C for more than 8 hours can reverse vernalization	Evans *et al.*, 1975
Rice	Temperature >35°C for more than 1 hour at anthesis causes high percentage spikelet sterility	Yoshida, 1981
Maize	Pollen begins to lose viability at temperatures >36°C	Decker *et al.*, 1986
Potato	Temperatures >20°C depress tuber initiation and bulking	Prange *et al.*, 1990
Soybean	Great ability to recover from temperature stress; critical period in its development unknown	Shibles *et al.*, 1975

Source: Acock and Acock, 1993.

Other environmental changes will interact with changes in climate variables and elevated CO_2 to affect crop yields. Among these are exposure to O_3—tropospheric (surface) concentrations of which have doubled over the past 100 years in the Northern Hemisphere (Feister and Warmbt, 1987; Volz and Kley, 1988; Anfossi *et al.*, 1991) to a level estimated to reduce yields in the range of 1 to 30% (e.g., Ashmore, 1988; Van der Eerden *et al.*, 1988; Bosac *et al.*, 1993; Sellden and Pleijel, 1993)—and exposure to ultraviolet-B (UV-B) radiation, which is expected to increase due to stratospheric ozone depletion. UV-B fluxes depend on cloud cover (Van der Leun and Tevini, 1991) and decrease by a factor of 10 with latitude and increase with altitude. Thus, crops grown at high latitudes and high altitudes are most likely to be affected. Plant sensitivities vary widely by species (Rozema *et al.*, 1991; Tevini, 1993) and across cultivars of species, such as soybeans (Biggs *et al.*, 1981).

Some studies have investigated the combined effect of various stresses including climate, CO_2, O_3, and UV-B on crops (e.g., Goudriaan and De Ruiter, 1983; Chaudhuri *et al.*, 1986; Allen, 1990; Mitchell *et al.*, 1993; Krupa and Kickert, 1993). Results indicate that rice, barley, sorghum, soybean, oats, beans, and peas are relatively more sensitive to UV-B than other major crops and that wheat, maize, potatoes, cotton, oats, beans, and peas are relatively more sensitive to O_3. For other crops, including cassava, sugar cane, sweet potato, grapes, coconut, rye and peanuts, no clear results are available.

Consistent moisture availability throughout the crop growth period is critical. Overall, the hydrological cycle is expected to intensify with higher evaporation, air humidity, and precipitation. Higher temperatures would, at the same time, increase crop water demand. Global studies have found a tendency for increased evaporative demand to exceed precipitation increase

Box 13-1. Modeling Crop Response to Environmental Change

Climatic and other factors strongly interact to affect crop yields. Models have provided an important means for integrating many different factors that affect crop yield over the season (Rötter, 1993). Scaling up results from detailed understanding of leaf and plant response to climate and other environmental stresses to estimate yield changes for whole farms and regions, however, can present many difficulties (e.g., Woodward, 1993).

Higher-level, integrated models typically accommodate only first-order effects and reflect more complicated processes with technical coefficients. Mechanistic crop growth models take into account (mostly) local limitations in resource availability (e.g., water, nutrients) but not other considerations that depend on social and economic response, such as soil preparation and field operations, management of pests, and irrigation.

Models require interpretation and calibration when applied to estimating commercial crop production under current or changed climate conditions (see Easterling *et al.*, 1992; Rosenzweig and Iglesias, 1994); in cases of severe stress, reliability and accuracy in predicting low yields or crop failure may be poor. With regard to the CO_2 response, recent comparisons of wheat models have shown that even though basic responses were correctly represented, the quantitative outcome between models varied greatly. Validation of models has been an important goal (Olesen and Grevsen, 1993; Semenov *et al.*, 1993a, 1993b; Wolf, 1993a, 1993b; Delecolle, 1994; Iglesias and Minguez, 1994; Minguez and Iglesias, 1994).

Further integration of models of crop yield, phenology, and water use with geographic-scale agroclimatic models of crop distribution and economic response has also occurred (e.g., Kaiser *et al.*, 1993; Kenny *et al.*, 1993; Rötter and van Diepen, 1994). Simplified representations of crop response have been used with climate and soil data that are available on a global basis (Leemans and Solomon, 1993). More aggregated statistical models have been used to estimate the combined physical and socioeconomic response of the farm sector (Mendelsohn *et al.*, 1994; Darwin *et al.*, 1995).

Incorporation of the multiple effects of CO_2 in models has generally been incomplete. Some do not include any CO_2 effects and thus may overestimate negative consequences of CO_2-induced changes in climate. Other models consider only a crude yield effect. More detailed models consider CO_2 effects on water use efficiency (e.g., Wang *et al.*, 1992; Leuning *et al.*, 1993). With few exceptions, most models fail to consider CO_2 interactions with temperature and effects on reproductive growth (Wang and Gifford, 1995).

in tropical areas (Rosenzweig and Parry, 1994), but this result varies locally and across climate scenarios. Large changes in the seasonal pattern of rainfall or changes in the consistency of rainfall within the crop growing season would likely matter more for annual crops than changes in annual precipitation and potential evaporation rates. Some studies suggest increased intensity of rainfall, which may result in increased runoff (Whetton *et al.*, 1993). Changes in large-scale atmospheric patterns such as the El Niño/Southern Oscillation (ENSO) and tropical monsoons could cause significant shifts in rainfall patterns, with consequent effects on agricultural production. ENSO events currently have widespread and well-documented impacts on production in Oceania, Latin America, Africa, South and Southeast Asia, and the United States (Folland *et al.*, 1990, 1991; McKeon *et al.*, 1990; Nicholls and Wong, 1990; McKeon and White, 1992; Rimmington and Nicholls, 1993), but climate scientists have not resolved how ENSO events may be affected by long-term climate change.

A variety of models (see Box 13-1) that integrate understanding of crop yield and climate relationships have been used for estimating changes in potential crop yield, zonal production shifts, and regional and global production (see Sections 13.5 and 13.8.2).

13.3. Soil Changes and Agricultural Practices

Climate affects most major soil processes and is a major factor in soil formation; the potential effects of changing climate and higher atmospheric CO_2 on soils are highly interactive and complex (Bouwman, 1990; Buol *et al.*, 1990). Many of the world's soils are potentially vulnerable to soil degradation (e.g., loss of soil organic matter, leaching of soil nutrients, salinization, and erosion) as a likely consequence of climate change (see Chapter 4).

Cropping practices that maintain a more closed ground cover over longer periods—including crop rotation, planting of cover crops, and reduced or minimum tillage—combined with integrated nutrient management are quite effective in combating or reversing current land degradation and would be similarly effective where climate change had the potential to exacerbate land degradation (Brinkman and Sombroek, 1993; Rasmussen and Collins, 1991; Logan, 1991). Brinkman and Sombroek (1993) found that, in most cases, changes in soils by direct human action, whether intentional or unintended, are likely to have a greater impact than climate change. They found that under a transient scenario of climate change, soil physical, chemical, and biological processes will be given time to adapt, thereby counteracting human-induced land degradation.

13.4. Weeds, Insects, and Diseases

Weeds, insects, and pathogen-mediated plant diseases are affected by climate and atmospheric constituents. Resultant changes in the geographic distribution of these crop pests and their vigor in current ranges will likely affect crops. Existing research has investigated climatic determinants of the range of many pests, but the potential changes in crop losses due to climatically driven changes in pests have not been included in most agricultural impact studies (Waggoner, 1983; Stinner *et al.*, 1987; Prestidge and Pottinger, 1990).

13.4.1. Weeds

Weeds will benefit from the "CO_2 fertilization effect" and from improvements in water use efficiency associated with increasing CO_2 concentrations, but the impact on crop production will depend on how enhanced-growth weeds compete with enhanced-growth crops. Of the 86 plant species that contribute 90% of per capita food supplies worldwide, 80 are C_3 plants (Prescott-Allen and Prescott-Allen, 1990), while 14 of the world's 18 worst weeds are C_4 plants (Holm *et al.*, 1977). Experiments generally show C_3 species to benefit from CO_2 enrichment at the expense of C_4 species (Patterson and Flint, 1980, 1990; Carter and Peterson, 1983; Patterson *et al.*, 1984; Wray and Strain, 1987; Bazzaz and Garbutt, 1988).

Regarding temperature, most weeds of warm season crops originate in tropical or warm temperate areas and are responsive to small increases in temperature. For example, the growth of three leguminous weeds increased significantly as day/night temperature increased (Flint *et al.*, 1984). Biomass of C_4 smooth pigweed (*Amaranthus hybridus*) increased by 240% for an approximate 3°C temperature increase; C_4 grasses also showed large increases (Flint and Patterson, 1983; Patterson, 1993).

Accelerated range expansion of weeds into higher latitudes is likely (Rahman and Wardle, 1990; Patterson, 1993) as demonstrated for itchgrass (*Rottboellia cochinchinensis*, Lour.), cogongrass (*Imperata cylindrica*), Texas panicum (*Panicum texanum*), and witchweed (*Striga asiatica*) (Patterson *et al.*, 1979; Patterson, 1995). However, not all exotic weeds will be favored by climatic warming. Patterson *et al.* (1986) found loss of competitiveness under warmer conditions for the southward spread of wild proso millet (*Panicum miliaceum*) in the southwestern United States.

Increasing CO_2 and climate change probably will also affect mechanical, chemical, and natural/biological efforts to control weeds (Patterson, 1993, 1995), which currently cause worldwide crop production losses of about 12% (25% for traditional production systems) (Parker and Fryer, 1975). Environmental factors including temperature, precipitation, wind, soil moisture, and atmospheric humidity influence when herbicides are applied, as well as their uptake and metabolism by crops and target weeds (Hatzios and Penner, 1982; Muzik, 1976). High leaf starch concentrations, which commonly occur in C_3 plants grown under CO_2 enrichment (Wong, 1990), might interfere with herbicide activity. CO_2 enrichment also increases the growth of rhizomes and tubers in C_3 plants (Oechel and Strain, 1985), which could reduce the effectiveness of chemical and mechanical control of deep-rooting, perennial C_3 weeds. On the other hand, increased temperatures and increased metabolic activity tend to increase uptake, translocation, and effectiveness of many herbicides. Natural and biological control of weeds and other pests depends on the synchrony between the growth, development, and reproduction of biocontrol agents and their targets. Such synchrony may be disrupted if climate changes rapidly, particularly if climatic extremes occur more frequently. Global warming could facilitate overwintering of insect populations and favor earlier poleward migrations in the spring, which could increase the effectiveness of biological control of weeds in some cases. Conversely, such enhanced over-winterings would accelerate the spread of viruses by migrating vectors like aphids.

13.4.2. Insect Activity and Distributian

Climate change will affect the distribution and degree of infestation of insect pests through both direct effects on the life cycle of insects and indirectly through climatic effects on hosts, predators, competitors, and insect pathogens. There is some evidence that the risk of crop loss will increase due to poleward expansion of insect ranges. Insect populations faced with modified and unstable habitats created under annual arable agricultural systems generally must diapause (enter a state of dormancy), migrate, otherwise adapt genetically, or die. Insect species characterized by high reproduction rates are generally favored (Southwood and Comins, 1976). Human alteration of conditions that affect host plant survival—irrigation, for example—also affects phytophagous (leaf-eating) insect populations.

Insect life cycle processes affected by climate and weather include lifespan duration, fecundity, diapause, dispersal, mortality, and genetic adaptation. Porter *et al.* (1991) list the following effects of temperature on insects: limiting geographical ranges; over-wintering; population growth rates; number of generations per annum; length of growing season; crop-pest synchronization; interspecific interactions; dispersal and migration; and availability of host plants and refugia. The effects of climate and weather on insect life cycles have been documented for a wide variety of insect pests of agriculture, rangelands, and forests (Dobzhansky, 1965; Fye and McAda, 1972; Tauber *et al.*, 1986; Mattson and Haack, 1987; Kingsolver, 1989; Cammell and Knight, 1991; Harrington and Stork, 1995). Many effects involve changes in the severity of outbreaks following extreme weather events (on the order of hours to weeks). Freezing temperatures are a major factor in mortality, but *Drosophila* sp. insects that survive relatively colder temperatures have been found to be more fecund than cohorts that were not exposed to the low temperatures (Dobzhansky, 1965). Temperatures that exceed critical thresholds frequently have adverse effects on fecundity, as in the cases of bollworm, *Helicoverpa zea* (Boddie); tobacco budworm, *Heliothis virescens* (F.); beet armyworm, *Spodoptera exigua* (Hübner); cabbage looper, *Trichoplusia ni* (Hübner); saltmarsh caterpillar, *Estigmene acrea* (Drury); and pink bollworm, *Pectinophora gossypiella* (Saunders) (Fye and McAda, 1972).

Abnormally cool, wet conditions are associated with high subsequent infestations of cotton by cotton tipworm, *Crocidosema plebejana* (Zeller) (Hamilton and Gage, 1986). November precipitation and April temperature are the best indicators of mean grasshopper densities in Southern Idaho (Fielding and Brusven, 1990). Drought can affect various physiological processes of plants, which may increase the plants' attractiveness and susceptibility to phytophagous insects (Mattson and Haack, 1987). Intense precipitation has been noted as a deterrent to the occurrence and success of oviposition by insects such as the European corn borer, *Ostrinia nubilalis* (Hübner) (Davidson and Lyon, 1987). Abundant precipitation can affect mortality, for example, through drowning of soil-dwelling insects (Watt and Leather, 1986) but is more likely to affect insects indirectly through climatic effects on insect pathogens, predators, and parasites, as has been shown for *H. zea* pupae especially under persistently saturated soil conditions (Raulston *et al.*, 1992).

While the specific ways in which climate change could affect persistent wind patterns such as nocturnal wind jets in the United States and convergence systems such as the Inter-Tropical Convergence Zone (ITCZ) are poorly predicted by GCMs, changes in the strength, timing, and geographical extent of these systems have been hypothesized. Important insect pests of agriculture currently use these systems to disperse widely from decaying habitats to viable habitats (Pedgley, 1982). Corn earworm, *H. zea* moths in the United States (Westbrook *et al.*, 1985; Scott and Achtemeier, 1987; Lingren *et al.*, 1993), grasshoppers or locusts [*Ailopus simulatrix* (Walker)], old world bollworm [*Heliathis armigera* (Hübner)], and whitefly [*Bemisia tabaci* (Gennadius)] disperse via atmospheric transport. In the case of the ITCZ and locusts, the winds also contribute ephemeral precipitation for host plants as reviewed by Joyce (1983) and Rainey (1989). Changes in these systems would affect the speed and range of dispersal of these pests.

Many of the documented effects of climate on insects are based on unusual weather events affecting the severity of insect outbreaks within their normal range or the (unintended) introduction of exotic species into new environments or extension of (host) crops into new environments (e.g., through irrigation). Human-induced local climate change within urban areas provides evidence of how insects can adapt to changes in their environment. Examples of genetic adaptation include: froggatt (*Dacus tryani*), lucerne flea (*Sminthurus viridis* L.) and sheep blowfly (*Lucilia cuprina*) (Wied.) in Australia after introduction from Europe or with the expansion of crop areas; the European corn borer, *O. nubilalis* (Hübner) and the European spruce sawfly, *Gilpinia hercyniae* (Hartig) in North America after introduction from Europe; and *Drosophila serrata* Mallock across latitudes (Birch, 1965). *Drosaphila serrata* Mallock also has responded by natural selection to the changed conditions in large cities (Dobzhansky, 1965). Selection to tighten host-insect interaction [such as codling moth, *Cydia pomonella* (L.), in fruit trees] appears to favor the evolution of isolated host races (Poshly and Bush, 1979). Climatic, agronomic, political, and economic factors jointly led to populations of boll weevil, *Anthonomus grandis grandis* Boheman, which adapted differently across cotton areas in the United States (Terranova *et al.*, 1990). Although insect populations have been redistributed during periods of major climatic change, a continuous intermixing of beetle species' gene pools in the Rocky Mountains of the United States was determined to have prevented speciation (Elias, 1991).

Understanding of insect physiological development and behavior has led to the development of numerical models that estimate insect growth, movement, and mortality in response to potential changes in climate (Goodenough and McKinion, 1992). Minimum and maximum temperatures, required cumulative degree days, and, where important, the effects of drought or wet conditions (which are the basis for such models), have been established for many common agricultural pests (e.g., Fye and McAda, 1972; Davidson and Lyon, 1987). Simulation models predict potential redistribution of insects under simulated climates.

Specific studies of the likely impacts of climate change were reviewed by Cammel and Knight (1991), Porter *et al.* (1991), Sutherst (1990, 1991), and Sutherst *et al.* (1995). They demonstrate that impacts could be severe in many different environments and involve numerous different species of insect pests. Principal concern is with species that can increase their population size by undergoing an extra generation each year in warmer climates or expand their geographical distributions. For example, Porter *et al.* (1991) found that in Europe *O. nubilalis* would shift 1220 km northward if temperature increased by 3° to 6°C by 2025–2070. For a 3°C temperature increase in Japan, Mochida (1991) predicted expanded ranges for tobacco cut worm (*Spodoptera litura*), southern green stink bug (*Nezera viridula*), rice stink bug (*Lagynotamus eleongatus*), lima-bean pod borer (*Etiella zinckenella*), common green stink bug (*Nezera antennata*), soybean stem gall (*Asphondylia sp.*), rice weevil (*Sitophilus oryzae*), and soybean pod borer (*Legumunuvora glycinivarella*), but a decreased range for rice leaf beetle (*Oulema oryzae*) and rice leaf miner (*Agromyza oryzae*). Vegetation subzones were linked with microclimates to extrapolate spruce weevil hazard zones in British Columbia (Spittlehouse and Sieben, 1994). Models that match the presence of particular species with discrete ranges of temperature and precipitation parameters such as CLIMEX may be especially appropriate for projecting the effects of climate change on insect redistribution (Worner, 1988; Sutherst *et al.*, 1995).

Actual insect distributions under climate change will also depend on host distributions (Rainey, 1989), competition with existing species (DeBach, 1965), adaptability to new conditions, and the presence of natural enemies in the area. Because climate effects on insect life cycles frequently depend on extreme events (e.g., freezing, intense precipitation) and climatic features such as the persistent winds of the Inter-Tropical Convergence system, the reliability of predicted redistribution of insects depends, in part, on the reliability of predictions of these features of climate.

13.4.3. Plant Diseases

The occurrence of plant fungal and bacterial pests depends on temperature, rainfall, humidity, radiation, and dew. Climatic conditions affect the survival, growth, and spread of pathogens, as well as the resistance of hosts. Friedrich (1994) summarizes the observed relationship between climatic conditions and important plant diseases. Among these, mild winters have been associated with more rapid and stronger outbreaks of powdery mildew (*Erysiphe grammis*), brown leaf rust of barley (*Puccinia hordei*), and strip rust of cereals (*Puccinia striiformis*) (Meier, 1985). Mild winters combined with very warm weather conditions provide optimal growth conditions for cercosporea leaf spot disease (*Cercosporea beticola*), powdery mildew (*Erysiphe betae*), and rhizomania disease (*Rizomania*) (Treharne, 1989). Warm, humid conditions lead to earlier and stronger outbreaks of late potato blight (*Phytophthora infestans*) (Löpmeier, 1990; Parry *et al.*, 1990). Dry and hot summers generally reduce infestations of most fungal diseases because plant resistance is increased. Summer dryness, particularly in early summer, also decreases rhynchosporium leaf blotch (*Rhynchosporium secalis*) and septoria leaf spot diseases (*Septoria tritici* and *S. nodorum*), but more frequent summer precipitation, particularly heavy storms, would increase incidences of these diseases because rain and rainborne splash water is the means by which disease spores are spread (Royle *et al.*, 1986). Warmer temperatures would likely also shift the occurrence of these diseases into presently cooler regions (Treharne, 1989).

13.5. Animal Agriculture

Climate affects animal agriculture in four ways: through (1) the impact of changes in livestock feedgrain availability and price (e.g., Adams *et al.*, 1990; Bowes and Crosson, 1993; Kane *et al.*, 1993; Rosenzweig and Parry, 1994); (2) impacts on livestock pastures and forage crops (Wilson, 1982; Martin *et al.*, 1991; Easterling *et al.*, 1993; McKeon *et al.*, 1993); (3) the direct effects of weather and extreme events on animal health, growth, and reproduction (Bianca, 1970; Rath *et al.*, 1994); and (4) changes in the distribution of livestock diseases (Stem, 1988, U.S. EPA, 1989).

Generally, the impacts of changes in feedgrain prices or forage production on livestock production and costs are moderated by markets. Impacts of changes in feedgrain supply on the supply of meat, milk, egg, and other livestock products in terms of price increase is substantially less than the initial feedgrain price shock (Reilly *et al.*, 1994). Bowes and Crosson (1993) demonstrated the importance of feed exports or imports into a region in determining downstream impacts on livestock and meatpacking industries. Abel and Levin (1981) found that, for developing country agriculture, livestock are a better hedge against losses than are crops because animals are better able to survive extreme weather events such as drought. The relatively lower sensitivity of livestock to climate change is also documented for the historical case of the U.S. Dust Bowl experience of the 1930s (Waggoner, 1993).

The impact of climate on pastures and unimproved rangelands may include deterioration of pasture quality toward poorer quality, subtropical (C_4) grasses in temperate pastoral zones as a result of warmer temperatures and less frost, or increased invasion of undesirable shrubs—but also potential increases in yield and possible expansion of area if climate change is favorable and/or as a direct result of increasing CO_2 (Martin *et al.*, 1993; McKeon *et al.*, 1993; Salinger and Porteus, 1993; Campbell *et al.*, 1995). (See Chapter 2 for details on possible changes in species composition of rangelands and effects on pastoral agriculture.)

Heat stress has a variety of detrimental effects on livestock (Furquay, 1989), with significant effects on milk production and reproduction in dairy cows (Johnston, 1958; Thatcher, 1974; Khan, 1991; Orr *et al.*, 1993). Swine fertility shows seasonal variation due to seasonal climate variability (Claus and Weiler, 1987). Reproductive capabilities of dairy bulls and boars and conception in cows are affected by heat stress (Egbunike and Elmo, 1978; Cavestany *et al.*, 1985; Berman, 1991). Livestock management and development of breeds better-suited to tropical climates has been a specific consideration (Bonsma, 1949; Du Preez *et al.*, 1990).

Analyses suggest that warming in the tropics and in the subtropics during warm months would likely impact livestock reproduction and production negatively (e.g., reduced animal weight gain, dairy production, and feed conversion efficiency) (Hahn *et al.*, 1990; Baker *et al.*, 1993; Klinedinst *et al.*, 1993; Rath *et al.*, 1994). Results are mixed for impacts in temperate and cooler regions: forage-fed livestock generally do better (due to more forage) but more capital-intensive operations, like dairy, are negatively affected (Parry *et al.*, 1988; Baker *et al.*, 1993; Klinedinst *et al.*, 1993). Warming during the cold periods for temperate areas would likely be beneficial to livestock production due to reduced feed requirements, increased survival of young, and lower energy costs.

Impacts may be minor for relatively intense livestock production systems (e.g., confined beef, dairy, poultry, swine) because such systems control exposure to climate and provide opportunity for further controls (e.g., shading, wetting, increasing air circulation, air conditioning, and alterations of barns and livestock shelters). Livestock production systems that do not depend primarily on grazing are less dependent on local feed sources, and changes in feed quality can be corrected through feed supplements. The fact that livestock production is distributed across diverse climatic conditions from cool temperate to tropical regions provides evidence that these systems are adaptable to different climates.

Many studies of climate and weather impacts on livestock find that the principal impacts are an increased role for management, adoption of new breeds in some cases where climate changes are moderate (for example, Brahman cattle and Brahman crosses are more heat- and insect-resistant than breeds now dominant in Texas and Southern Europe), and introduction of different species in some cases of extreme weather changes (Entwistle, 1974; Hahn, 1988, 1994; Hahn *et al.*, 1990; Baker *et al.*, 1993; Baker, 1994; Klinedinst *et al.*, 1993; Rath *et al.*, 1994).

13.6. Regional Climate Impacts: Studies and Issues

Variation of agriculture systems, climates, resources, and economic characteristics across and within countries may be more important in determining the effects of climate change than differences in climate scenarios themselves. Agricultural policy is an important consideration in most regions. Agricultural policies have had many and changing goals. Climate change is generally not among top policy priorities for agricultural policymakers, but climate change could affect the cost and likelihood of achieving other policy priorities—such as food adequacy and reduction of chronic hunger, improving export competitiveness, assuring regional and national economic and social development, increasing farm income and the viability of rural communities, assuring water availability and quality, reducing or reversing land degradation and soil loss through erosion, and other conservation and environmental objectives.

13.6.1. Africa and the Middle East

While Africa, particularly sub-Saharan Africa, is highly dependent on agriculture, relatively little quantitative work has been done on the impacts of climate change. Little or no effort has been devoted to studying agricultural effects on countries of the Middle East. The available studies for sub-Saharan Africa suggest that critical thresholds are related to precipitation and the length of the growing season, although warmer temperatures and increased radiation may benefit highland areas. National and local assessments providing a detailed understanding of crop-specific responses and regional impacts are still lacking.

Recent studies (Ominde and Juma, 1991; Ottichilo *et al.*, 1991; Downing, 1992; Schulze *et al.*, 1993; Sivakumar, 1993; Magadza, 1994) indicate that most of Africa will be sensitive to climate change, although some regions may benefit from warmer and wetter conditions (Table 13-4). Downing (1992), in analyses for Kenya, Zimbabwe, and Senegal, evaluated the sensitivity to incremental climatic variations suggested by GCM scenarios for the region. Nationally, he estimated that potential food production in Kenya would increase, particularly if rainfall increases, but that the impacts would vary regionally; sub-humid and semi-arid provinces supporting socioeconomically vulnerable groups would be negatively affected even with increases in national food production potential.

Table 13-4: Selected crop studies for Africa and the Middle East.

Study	Scenario	Geographic Scope	Crop(s)	Yield Impact (%)	Other Comments
Eid, 1994	GISS, GFDL, UKMO	Egypt	Wheat Maize	-75 to -18 -65 to +6	w/ CO_2 effect; also temperature and precip. sensitivity; adaptation would require heat-resistant variety development
Schulze *et al.*, 1993	+2°C (1)	South Africa	Biomass Maize	decrease increase	Mapped results, not summarized as average change for entire region
Muchena, 1994	GISS, GFDL, UKMO	Zimbabwe	Maize	-40 to -10	w/ CO_2 effect; also temperature and precip. sensitivity; adaptations (fertilizer and irrigation) unable to fully offset yield loss
Downing, 1992	+2/+4°C, ±20% precip.	Zimbabwe Senegal Kenya	Maize Millet Maize	-17 to -5 -70 to -63 decrease	Food availability estimated to decline in Zimbabwe; carrying capacity fell 11 to 38% in Senegal; overall increase for all crops in Kenya with zonal shifts
Akong'a *et al.*, 1988	Historical droughts, sensitivity	Kenya	Maize, livestock	negative effects of drought	Considered broader socioeconomic impacts, small-holder impacts, and policy implications
Sivakumar, 1993	1945–64 vs. 1965–88	Niger, West Africa	Growing season	reduced 5–20 days	Crop variety development, timely climate information seen as important adaptation strategies

Akong'a *et al.* (1994) and Sivakumar (1993) considered the effects of climatic variability (primarily periodic droughts) on agriculture in some areas of the region, finding that such droughts have significant negative effects on production, crop season length, and higher-order social impacts. The persistence of such periodic droughts and the potential for them to change in frequency and severity in the Sahel and in eastern and southern Africa indicate the need for further research to develop adaptive strategies. The effects of greater frequency and severity include growing aridity in the savannas; deforestation and soil erosion in all farming systems but particularly in the humid, sub-humid, and equatorial regions; and salinization of irrigated lands. The economies of countries of North Africa and the Middle East are generally less dependent on agriculture than are those of sub-Saharan Africa. One study for Egypt (Eid, 1994) indicated the potential for severe impacts on national wheat and maize production.

13.6.2. South and Southeast Asia

South and Southeast Asia include the southern portion of Asia, from Pakistan in the west to Vietnam in the east, as well as Indonesia and the Philippines. Seasonal monsoons are a dominant climate feature that affect agriculture. Matthews *et al.* (1994a, 1994b) have estimated the impacts on rice yields for many countries in the region for equilibrium climate scenarios of three major GCMs that predict temperature and precipitation increases for the region. The results show substantial variation in impact across the region and among the GCMs (Table 13-5).

Table 13-5: Selected crop studies for South and Southeast Asia.

Study	Scenario	Geographic Scope	Crop(s)	Yield Impact (%)	Other Comments
Rosenzweig and Iglesias (eds.), 1994[1]	GCMs	Pakistan	Wheat	-61 to +67	UKMO, GFDL, GISS, and +2°C, +4°C, and ±20% precip; range is over sites and GCM scenarios with direct CO_2 effect; scenarios w/o CO_2 and w/ adaptation also were considered; CO_2 effect important in offsetting losses of climate-only effects; adaptation unable to mitigate all losses
		India	Wheat	-50 to +30	
		Bangladesh	Rice	-6 to +8	
		Thailand	Rice	-17 to +6	
		Philippines	Rice	-21 to +12	
Qureshi and Hobbie, 1994	average of 5 GCMs	Bangladesh	Rice	+10	GCMs included UKMO, GFDLQ, CSIRO9, CCC, and BMRC; GCM results scaled to represent 2010; includes CO_2 effect
		India	Wheat	decrease	
		Indonesia	Rice	-3	
			Soybean	-20	
			Maize	-40	
		Pakistan	Wheat	-60 to -10	
		Philippines	Rice	decrease	
		Sri Lanka	Rice	-6	
			Soybean	-3 to +1	
			Coarse Grain	decrease	
			Coconut	decrease	
Parry *et al.*, 1992	GISS	Indonesia	Rice	approx. -4	Low estimates consider adaptation; also estimated overall loss of farmer income ranging from $10 to $130 annually
			Soybean	-10 to increase	
			Maize	-65 to -25	
		Malaysia	Rice	-22 to -12	
			Maize	-20 to -10	Maize yield affected by reduced radiation (increased clouds); variation in yield increases; range is across seasons
			Oil Palm	increase	
			Rubber	-15	
		Thailand sites	Rice	-5 to +8	
Matthews *et al.*, 1994a, 1994b	3 GCMs	India	Rice	-3 to +28	Range across GISS, GFDL, and UKMO GCM scenarios and crop models; included direct CO_2 effect; varietal adaptation was shown to be capable of ameliorating the detrimental effects of a temperature increase in currently high-temperature environments
		Bangladesh		-9 to +14	
		Indonesia		+6 to +23	
		Malaysia		+2 to +27	
		Myanmar		-14 to +22	
		Philippines		-14 to +14	
		Thailand		-12 to +9	

[1] Country studies were by Qureshi and Iglesias, 1994; Rao and Sinha, 1994; Karim *et al.*, 1994, Tongyai, 1994; and Escaño and Buendia, 1994, for Pakistan, India, Bangladesh, Thailand, and the Philippines, respectively.

Spikelet sterility emerged as a major factor determining the differential predictions; where current conditions were near critical thresholds, a difference in mean temperature of less than a degree resulted in a positive yield change rapidly becoming a large decline. However, genetic variability among varieties suggests relative ease in adapting varieties to new climate conditions. Temperature effects alone were generally found to reduce yields, but CO_2 fertilization was a significant positive effect.

Brammer *et al.* (1994) conclude that, among other things, the diversity of cropping systems does not allow a conclusion of magnitude or direction of impact to be made for Bangladesh at this time. Parry *et al.* (1992) showed yield impacts that vary across the countries of Thailand, Indonesia, and Malaysia and across growing season. Coastal inundation was also estimated to be a threat to coastal rice and to fish, prawn, and shrimp ponds. These authors estimated that a 1-meter sea-level rise could cause a landward retreat of 2.5 km in Malaysia; such a rise was estimated to threaten 4200 ha of productive agricultural land, an area equal to slightly less than 1% of Malaysia's paddy rice area. Model results showed that under Goddard Institute for Space Studies (GISS) doubled CO_2 climates, erosion rates in three Malaysian river basins increased from 14–40%, and soil fertility declined on average by 2–8%.

13.6.3. East Asia

Several major studies have been conducted for countries in East Asia, including China (mainland and Taiwan), North and South Korea, and Japan. Possible climatic impacts span a wide range depending on the climate scenario, geographic scope, and study (Table 13-6). For China, results show generally negative yield effects but range from less than 10% (Zhang, 1993) to more than 30% (Jin *et al.*, 1994). While finding large changes for all of China, Hulme *et al.* (1992) conclude that to a certain extent, warming would be beneficial, with increasing yield due to diversification of cropping systems. However, they estimated that by 2050, when they expect an average warming for China of 1.2°C, increased evapotranspiration would generally exceed increases in precipitation, thus leading to a greater likelihood of yield loss due to water stress for some rice-growing areas, even as the area suitable for rice increases.

Table 13-6: *Selected crop studies for East Asia.*

Study	Scenario	Geographic Scope	Crops	Yield Impact (%)	Other Comments
Tao, 1992	2 x CO_2 +1°C	China	Wheat Rice Cotton, Fruits, Oil Crops, Potatoes, Corn	-8 -6 -4 to +1	Agricultural productivity loss >5%; included direct CO_2 effect; positive effects in NE and NW; negative in most of the country; no change in SW
Zhang, 1993	+1.5°C	South of China	Rice	-11 to -7	Double-crop; included direct CO_2 effect
Jin *et al.*, 1994	GCMs	South of China	Rainfed Rice Irrigated Rice	-78 to -6 -37 to +15	Range across GISS, GFDL, and UKMO scenarios; no consideration of enrichment effects of CO_2
Sugihara, 1991	2 x CO_2 +3°C	Japan	Rice	+10	
Suyama, 1988	+2°C	Japan	Temperate Grass	-10 to +10	Average +5.6% in productivity for grass; included direct CO_2 effect
Yoshino, 1991	+2°C	Japan	Sugar Cane	-8	Rainfall was reduced 25 to 30%, May to October
Seino, 1994	GISS, GFDL, UKMO	Japan	Rice Maize Wheat	-11 to +12 -31 to +51 -41 to +8	Impacts vary by GCM scenarios and area; included direct CO_2 effect; generally positive in N and negative in S
Horie, 1993	GCMs	Hiroshima and Akita, Japan	Rice	-45 to +30	Estimated 14% increase for all of Japan; range based on different crop models, GCMS, and across sites; included direct CO_2 effect; Akita more favorable than Hiroshima
Matthews *et al.*, 1994a, 1994b	GCMs	South Korea Mainland China Taiwan Japan	Rice	-22 to +14 -18 to -4 +2 to +28 -28 to +10	Range across GISS, GFDL, and UKMO scenarios and crop models; included direct CO_2 effect; varietal adaptation capable of ameliorating the effects of a temperature increase in currently hot environments

For China, warming would likely cause a general northward movement of agroclimatic regions, with certain exceptions in the south where the moisture deficit may increase even more than in the north. The general possibility of increased summer dryness in the continental mid-latitudes suggests the following six areas as most likely to be negatively affected by climate change (Lin Erda, 1994): the area around the Great Wall lying southeast of the transition belt between crop agriculture and animal husbandry; the Huang-Hai Plains where dryland crops like wheat, cotton, corn, and fruit trees are grown; the area north of Huai River including Eastern Shandong that lies along the south edge of the south temperate zone; the central and southern areas of Yunnan Plateau; middle and lower reaches of Yangtze River; and the Loess Plateau. In general, these areas would be at heightened risk of drought and would suffer potential increases in soil erosion. The Yunnan Plateau, with generally abundant rainfall, is subject to alternating droughts and waterlogging; production is sensitive to changes that would increase the variability of climate.

Indices of vulnerability based on physical productivity and socioeconomic capability to adapt show that among China's thirty provinces, Shanxi, Inner Mongolia, Gansu, Hebei, Qinghai, and Ningxia are particularly vulnerable and less able to adapt to climate change. These seven provinces produced 12% of China's total agricultural output value in 1990 (*Statistical Yearbook of Agriculture of China*, 1991). Thus, the areas along the Great Wall and Huang-Hai Plains are areas that are both socioeconomically and agronomically vulnerable to climate change and also are areas where climate projections suggest possible adverse changes in climate.

Climate change will occur against a steadily increasing demand for food in China over the next 55 years (Lu and Liu, 1991a, 1991b). The increased annual cost of government investment only (excluding farmers' additional costs) in agriculture due to climate change through 2050 was estimated at 3.48 billion U.S. dollars (17% of the cost of government investment in agriculture in 1990).

Studies for Japan (Table 13-6) indicate that the positive effects of CO_2 on rice yields would generally more than offset negative climatic effects in the central and northern areas, leading to yield gains; in the southwest, particularly in Kyushu, the rice yield effects were, on balance, estimated to be negative for several climate scenarios (Seino, 1993a, 1993b). Horie (1987) found generally negative effects on rice yield in Hokkaido under the GISS climate scenario when rice variety was not changed but found increased yields if longer maturing varieties were adopted. Horie (1991), under the Oregon State University (OSU) climate scenario, found that rice yields would fall in most areas of the country but that changes in rice variety and other management changes could recover most losses except in the southwest, where the projected increase in temperature of 4.0–4.5°C exceeded the temperature tolerances of japonica rice varieties. Additional considerations for Japanese agriculture are possible changes in flowering and maturation of fruit trees, with potential northward shifts in cultivated areas and changed distribution of insect pests (Seino, 1993a).

13.6.4. Oceania and Pacific Island Countries

Oceania includes Australia, New Zealand, Papua New Guinea, and numerous small islands and coral atolls of the Pacific Island Countries (PICs).

Findings for Australia include: (1) poleward shifts in production, (2) varying impacts on wheat including changes in grain quality, (3) likely inadequate chilling for stone fruit and pome fruit and lower fruit quality, (4) increased likelihood of heat stress in livestock, particularly dairy and sheep, (5) increased infestation of tropical and subtropical livestock parasites but possible decreases for other species, (6) livestock benefits due to warmer and shorter winters, (7) increased damage due to floods and soil erosion, (8) increased drought potential with wheat and barley more sensitive than oats, (9) changes in the severity of outbreaks of downy mildew on grapevines and rust in wheat, and (10) beneficial effects of elevated CO_2 levels for many agricultural crops (Hobbs *et al.*, 1988; Nulsen, 1989; Pittock, 1989; Wardlaw *et al.*, 1989; Blumenthal *et al.*, 1991; Wang *et al.*, 1992; CSIRO, 1993; Hennessy and Clayton-Greene, 1995; Wang and Gifford, 1995).

Studies of New Zealand agriculture considered the main effects of climate change on New Zealand's important pastoral agriculture to be: (1) a poleward spread of subtropical pastures, (2) a resultant decrease in the area of temperate pasture, (3) higher yields, (4) altered seasonality of production, (5) spread of growth to higher elevations, and (6) decreased growth in the eastern areas of the North Island due to drier and warmer conditions (Ministry for the Environment, 1990; Salinger and Hicks, 1990; Martin *et al.*, 1991). Models to predict effects on forage production systems are currently being developed and validated. Initial modeling simulations of the effects of doubled-CO_2 climates on pasture yield including the beneficial effects of CO_2 varied from +10 to +77% (Korte *et al.*, 1991; Butler *et al.*, 1991; Martin *et al.*, 1991). The higher figures, however, likely overestimated the beneficial effects of CO_2 (Campbell, 1994). More recent work (Campbell *et al.*, 1995; Newton *et al.*, in press) indicates gains of up to 15%.

Studies have found variable impacts on horticultural crops in New Zealand, with a general poleward shift, including an expansion of the area for subtropical crops but a contraction of area suitable for temperate crops such as apples and kiwi fruit that require winter chilling (Salinger *et al.*, 1990). Studies for maize suggest expansion of the suitable growing area into the Canterbury Plains of the South Island (Kenny *et al.*, 1994; Tate *et al.*, 1994; Warrick and Kenny, 1994).

For small island states, fewer studies have been conducted. Singh *et al.* (1990) conclude that, in general, crop yields would be lower because of reduced solar radiation (from increased cloudiness), higher temperature (leading to shorter growth duration and increased sterility), and water availability (both drought and inundation). Sea water intrusion also could affect some coastal areas. Some of the negative effects, particularly

Table 13-7: Selected studies for Australia and New Zealand.

Study	Scenario	Geographic Scope	Crops	Yield Impact (%)	Other Comments
Campbell, 1994; Campbell *et al.*, 1995; Newton *et al.*, in press	Various	New Zealand	Pasture	increase overall, but decrease in some regions	GCM scenarios and climate sensitivity result in yield increases w/ and w/o CO_2 fertilization; increases of up to 15% w/ CO_2 fertilization; earlier studies found larger increases, but likely overestimated the CO_2 effect; additional findings include altered seasonality of pasture with effects on livestock management
Salinger *et al.*, 1990	*	New Zealand	Temperate Crops and Pasture	increase	Crop shifts of 200m in altitude and 200km poleward; earlier crop maturation; longer frost-free season
McKeon *et al.*, 1988	+2°C, -20% winter precipitation, +30% rest	SW Queensland, Australia	Semi-Arid Perennial Grass, Wheat	+31 (-1, +35) +23 (-6, +35)	Temperature only (precipitation only in parentheses); no CO_2 effect; for grasslands, increased risk from undesirable shrubs and grasses, animal nutrition and health, and soil erosion; new areas may be available
Vickery *et al.*, 1993	+2°C, +10 to +20% precip. Nov. to March	Northern NSW, Australia	Cool Temperate Grazing	not assessed	Expansion of high NPP (3.2 to 4.8 t/ha) area from 59 to 64% of the region; soil and landscape as possible limiting factors not considered
Erskine *et al.*, 1991	GISS, GFDL, UKMO	S. Australia	Wheat	-6 to +13	Included CO_2 to 555 ppm; results w/o CO_2 were -15 to -16%; no varietal adaptation or other management change
Wang *et al.*, 1992	+3°C	Horsham, Victoria, Australia	Wheat	-34 to +65	Included CO_2 to 700 ppm; range across cultivars; losses occurred for early-maturing varieties and stemmed mainly from shortened vegetative growing period
Russel, 1988	+2 to +4°C	Queensland, Australia	Sugar Cane	+9 to +13	Southward expansion possible; also considered similar temperature declines; yields -40 to -17%

*Used climate scenarios as given in Salinger and Hicks (1990), which are mean changes derived from the results of several GCMs.

of C_3 crops, would be offset by the beneficial effects of elevated CO_2. No quantitative estimates of sensitivities or thresholds directly related to agriculture have been reported in major impact studies (e.g., Hughes and McGregor, 1990; Pernetta and Hughes, 1990; Hay and Kaluwin, 1992).

Singh (1994) considers the vulnerability of small island nations to some large changes in climatic conditions that, while not currently predicted by climate models, indicate sensitivities. Increasing aridity (reductions in rainfall and prolonged dry seasons) affecting small islands and the leeward side of bigger islands was estimated to result in general crop failure, migration of human populations, wind erosion, and negative impacts on wildlife. A somewhat less severe drying (prolonging the dry season by 45 days or more) would decrease yields of maize (30 to 50%), sugar cane (10 to 35%), and taro (35 to 75%). Singh (1994) also found that significantly increased rainfall (+50%) during the wet season on the windward side of large islands, while increasing yields of taro (5 to 15%), would reduce yields of rice (10 to 20%) and severely reduce maize yields (30 to 100%). Maize failures from increased precipitation stem from inundation, and rice yield losses stem from increased cloudiness (reduced solar irradiation).

13.6.5. Areas of the Former USSR

Climate impact studies conducted over the past 15 years include those of Zhukovsky and Belechenko (1988), Zhukovsky *et al.* (1992), and Sirotenko *et al.* (1984). These studies did not include the direct effect of increasing atmospheric CO_2. Recent estimates have included coverage of most of the region and have included the CO_2 effect (Menzhulin and Koval, 1994) and other environmental change (Sirotenko and Abashina, 1994; Sirotenko *et al.*, 1991). These new studies also have been the first conducted for this region based on climate scenarios drawn from GCM runs (Table 13-8).

Table 13-8: Selected crop studies for Russia and the former Soviet republics.

Study	Scenario	Geographic Scope	Crop(s)	Yield Impact (%)	Other Comments
Menzhulin and Koval, 1994	GISS, GFDL, UKMO	Russia and Former Soviet Republics	Winter and Spring Wheat	-19 to +41	Included CO_2 effect; GISS strongly positive, UKMO negative; temperature sensitivity alone of 2 and 4°C resulted in yield losses of 20 to 30%; impacts also varied widely across the 19 sites studied
Sirotenko and Abashina, 1994; Sirotenko *et al.*, 1991[1]	EMI	Russia	Crop Yield, Grassland Productivity	+10 to+35 -2 to +26	Large positive effect in Southern Volga and Northern Caucasus areas; slightly negative crop yield in S. Krasnoyarsky and Far East; range is w/ and w/o +20% CO_2, +30% tropospheric ozone, and -20% soil humus
	CCC, GFDL		Crop Yield, Grassland Productivity	-14 to +13 -27 to -2	

[1]These studies used a reconstructed Eemian Interglacial (EMI) climate and the Canadian Climate Centre (CCC) and Geophysical Fluid Dynamics Laboratory (GFDL) GCMs. The temperature and precipitation predictions of the GCMs were scaled by the factors 0.51 (CCC) and 0.45 (GFDL) to generate climates that could be observed by the year 2030.

Sirotenko and Abashina (1994) and Sirotenko *et al.* (1991) scaled the equilibrium temperature and precipitation derived from GCMs to generate scenarios applicable to the year 2030 and used the Eemian interglacial period (EMI) climate. In the EMI scenario, warming was greatest in January and precipitation increased substantially in both January and July, whereas the GCM scenarios suggested drier and warmer summer conditions. Changes in potential crop yield and potential productivity of grasses are based on a geoinformation system CLIMATE-SOIL-YIELD and a dynamic-growth crop simulation model (Sirotenko, 1981; Abashina and Sirotenko, 1986; Sirotenko, 1991) (Table 13-8). The results indicate that the climate response of crops and grasses can differ even in sign.

The estimated response of agriculture varied significantly across the region as well as across climate scenarios. Sirotenko and Abashina (1994) and Sirotenko *et al.* (1991) estimate the impacts to be favorable on agriculture of the northern areas of European Russia and Siberia and to cause a general northward shift of crop zones. Actual changes in production would reflect both areal expansion and the yield changes on existing crop areas as reported in Table 13-8. The more arid climate of the Canadian Climate Centre (CCC) and Geophysical Fluid Dynamics Laboratory (GFDL) GCMs was projected to have severe effects on grain production in the steppes of Povolzhye, Northern Caucasus, and the southern portion of Western Siberia, where grain production was estimated to fall by 20–25%. Menzhulin and Koval (1994) simulated yield increases exceeding 50% in the northwestern, central, and eastern regions of Kazakhastan under the GISS scenario, primarily because of increased moisture in these currently arid areas, but these areas did not benefit substantially under the GFDL scenario. Overall, the UK Meteorological Office (UKMO) scenario produced the largest yield declines.

Sirotenko and Abashina (1994) and Sirotenko *et al.* (1991) found that potential increases in ozone and loss of soil organic matter reduced potential yields substantially; when combined with the climate/CO_2 scenarios, grass yields declined by about one-quarter and crop yields by 10% in both CCC and GFDL GCM scenarios. Kovda and Pachepsky (1989) report the potential for significant additional soil loss and degradation resulting from climate change.

Historically, climate variability has been a significant contributor to yield variability in areas of the former USSR. For example, the increase in aridity during the 1930s was estimated to have decreased yields by 25–39% (Menzhulin, 1992). If drier conditions prevail under climate change, similar yield effects may occur.

13.6.6. Latin America

Climate impact studies for Latin America that include the direct effect of CO_2 generally show negative impacts for wheat, barley, and maize but positive impacts for soybeans (Table 13-9). A study of Norte Chico, Chile, suggested decreased yields for wheat and grapes but increases for maize and potatoes (Downing, 1992). The Norte Chico results are difficult to generalize because the climate for Chile exhibits steep temperature gradients from east to west due to the change in altitude, as well as wide variation from north to south.

The largest area with clear vulnerability to climate variability in the region is the Brazilian northeast. Like most agricultural areas of Latin America, this region has a rainy season when crops are grown and a dry season with little or no rain. In the case of the Brazilian northeast, the rainy season is relatively short (3–4 months) and the occurrence of years with no rainy season is frequent. These years are characterized by the occurrence of famine and large-scale migrations to metropolitan areas. Climatic variations that would result in shorter rainy seasons and/or increased

Table 13-9: Selected crop studies for Latin America.

Study	Scenario	Geographic Scope	Crop(s)	Yield Impact (%)	Other Comments
Baethgen, 1992, 1994	GISS, GFDL, UKMO[1]	Uruguay	Barley Wheat	-40 to -30 -30	w/ and w/o CO_2; with adaptation, losses were 15 to 35%; results indicate increased variability
Baethgen and Magrin, 1994	UKMO	Argentina Uruguay	Wheat	-10 to -5	w/ CO_2; high response to CO_2, high response to precipitation
Siquera *et al.*, 1994; Siquera, 1992	GISS, GFDL, UKMO[1]	Brazil	Wheat Maize Soybean	-50 to -15 -25 to -2 -10 to +40	w/ CO_2, w/o adaptation; adaptation scenarios did not fully compensate for yield losses; regional variation in response
Liverman *et al.*, 1991, 1994	GISS, GFDL, UKMO[1]	Mexico	Maize	-61 to -6	w/ CO_2; adaptation only partly mitigated losses
Downing, 1992	+3°C, -25% precip.	Norte Chico, Chile	Wheat Maize Potatoes Grapes	decrease increase increase decrease	The area is especially difficult to assess because of the large range of climates within a small area
Sala and Paruelo, 1992, 1994	GISS, GFDL, UKMO[1]	Argentina	Maize	-36 to -17	w/ and w/o CO_2; better adapted varieties could mitigate most losses

[1]These studies also considered yield sensitivity to +2 and +4°C and -20 and +20% change in precipitation.

frequency of rainless years would have extremely negative consequences for the region.

13.6.7. Western Europe

Simulated yields of grains and other crops have been generally found to increase with warming in the north, particularly when adaptation is considered, but decrease substantially in the Mediterranean area even with adaptation (Table 13-10). Northern yield increases depend on the beneficial effects of CO_2 on crop growth and climate scenarios showing sufficient increases in precipitation to counter higher rates of evapotranspiration. Yield declines in the Mediterranean region are due to increased drought resulting from the combination of increased temperature and precipitation decreases (or insufficient increases to counter higher evapotranspiration).

For many vegetable crops, warmer temperatures will generally be beneficial, with the options and possibilities for vegetable production generally expanding in northern and western areas. For cool-season vegetable crops such as cauliflower, larger temperature increases may reduce the number of plantings possible during cooler portions of the year or decrease production, particularly in southern Europe (Kenny *et al.*, 1993; Olesen and Grevsen, 1993). Decreased yield quality is also possible, with the effect most pronounced in southern Europe.

Warmer winters will reduce winter chilling and probably adversely affect apple production in temperate maritime areas, and could lead to loss of adequate winter chilling for crops such as peaches, nectarines, and kiwi fruit in southern Europe. Significant shifts in areas suitable for different types of grapes also could occur (Kenny and Harrison, 1992).

Among other effects, warming implies reduction in greenhouse costs for horticultural production. However, increased infestations of pests such as the Colorado beetle on potatoes and rhizomania on sugar beet may result from higher temperatures.

Studies have investigated changes in crop potential evapotranspiration (PET) (Le Houerou, 1994; Rowntree, 1990), finding that under higher temperatures the crop growing season would be extended for grain crops, assuming an increase in the number of frost-free days. For southern Europe, the extension of the growing season would likely be insufficient to avoid high summer temperatures by planting earlier. Thus, reduced grain filling period and lower yields are likely. Other studies have explored how the climatically limited range for crops, including maize, wheat, cauliflower, and grapes, would change under various GCMs and other climate scenarios (Carter *et al.*, 1991a, 1991b; Parry *et al.*, 1992; Kenny *et al.*, 1993; Kenny and Harrison, 1993; Wolf, 1993a, 1993b). In general, these studies found a northward shift of crop-growing zones with potential for grain maize to be grown as far north as the UK and central Finland. Increased demand for irrigation and/or increased areas likely to suffer from water deficits, particularly in southern Europe, also were found.

13.6.8. USA and Canada

Studies listed in Tables 13-11 (USA) and 13-12 (Canada) show a wide range of impacts. Much of the wide variation reflects differences among sites. Effects are more likely negative or more severely negative for southern areas and for climate scenarios such as the UKMO GCM scenario in which the temperature increases are large (+5.2°C) or the GFDL scenario in which summer aridity increased.

Rosenzweig (1985) simulated increased areas for wheat production, especially in Canada, under the GISS climate change scenario, while major wheat regions in the United States remain the same (Rosenzweig, 1985). Crosson (1989) found that warmer temperatures may shift much of the wheat-maize-soybean producing capacity northward, reducing U.S. production and increasing production in Canada. Shifting climate zones may result in lower production of corn or wheat and different and more diverse crops because the productivity in the new areas is likely to be limited due to the shallow, infertile soils (CAST, 1992).

Across studies in Table 13-11 for the USA that combined biophysical and economic impacts, market adjustments lessen the impacts of negative yield changes. Different assumptions about changes in U.S. population, income, trade barriers, and institutions were found, in some cases, to determine whether the net economic impact of climate change on the USA was negative or positive. Kaiser *et al* (1993) found that possible increases in agricultural commodity prices could more than offset farm income loss. Mendelsohn *et al.* (1994) used an econometric approach to directly estimate the impact of climate change on agricultural revenue and asset values. This approach more fully considers potential adaptation to different climates as directly observed across climates that vary as a result of geography. They found that for the United States, warming would generally be beneficial even without the direct effect of CO_2. This approach calculates an equilibrium response after complete adjustment and does not consider price changes.

A number of studies have considered the vulnerability of prairie agriculture to climate change in Canada (Cohen *et al.*, 1992). Factors cited as contributing to vulnerability include the

Table 13-10: Selected crop studies for Western Europe.

Study	Scenario	Geographic Scope	Crop(s)	Yield Impact (%)	Other Comments
Oleson *et al.*, 1993	*	Northern Europe	Cauliflower	increase	Quality affected by temperature; longer season
Goudriaan and Unsworth, 1990	+3°C	Northern Europe	Maize (fodder)	increase	Shift to grain production possible
Squire and Unsworth, 1988	+3°C	Northern Europe	Wheat	increase	
Kettunen *et al.*, 1990	GCMs	Finland	Potential Yield	+10 to +20	Range is across GISS and UKMO GCMs
Rötter and van Diepen, 1994	+2°C (winter), +1.5°C (summer)	Rhine Area	Cereals, Sugar Beet, Potato, Grass	+10 to +30	Also +10% winter precipitation; includes direct effect of CO_2; range is across crop, agroclimatic zone, and soil type; decreased evapotranspiration (1 to 12%), except for grass
UK Dept. of Environment, 1992	GCMs +1, +2°C	UK	Grain Horticulture	increase or level increase	Increased pest damage; lower risk of crop failure
Wheeler *et al.*, 1993	*	UK	Lettuce	level	Quality affected; more crops per season possible
Semonov *et al.*, 1993	*	UK France	Wheat	increase or decrease	Yield varies by region; UKMO scenario negative; includes adaptation and CO_2
Delecolle *et al.*, 1994	GCMs** +2, +4°C	France	Wheat Maize	increase or level	Northward shift; w/ adaptation, w/ CO_2; GISS, GFDL, and UKMO GCMs
Iglesias and Minguez, 1993	GCMs**	Spain	Maize	-30 to -8	w/ adaptation, w/ CO_2; irrigation efficiency loss; see also Minguez and Iglesias, 1994
Santer, 1985	+4°C	Italy/Greece	Biomass	-5 to +36	Scenarios also included -10% precipitation
Bindi *et al.*, 1993	+2, +4°C and *	Italy	Winter Wheat	not estimated	Crop growth duration decreases; adaptation (using slower developing varieties) possible

* Climate scenarios included GISS, GFDL, and UKMO and time-dependent scenarios, using GCM methodology, based on emission scenarios proposed by the IPCC in 1990. Composite scenarios for temperature and precipitation were based on seven GCMs and scaled by the global-mean temperature changes associated with the IPCC 1990 emission scenarios for the years 2010, 2030, and 2050 (Barrow, 1993).

** These studies also considered yield sensitivity to +2 and +4°C and -20 and +20% change in precipitation.

prairie's importance as an agricultural producer, located in a marginal climate, constrained by both temperature and precipitation; soil limitations that limit shifting of cropping northward; known sensitivity to climate as evidenced by past drought experiences; and vulnerability to midcontinental drying indicated by GCMs. The effects of the 1988 drought are an indication of the region's sensitivity to climate variability. The effects included dust storms and wind erosion, production declines of 29% (grains) to 94% (hay), falling grain inventories, higher prices, poor pastures for livestock with some movement of cattle to moister areas, higher feed costs for livestock, and farm income reductions of 50% to 78% compared to 1987 figures.

13.7. Regional Summary: Relative Vulnerability

There has been a substantial number of new agricultural impact studies since the 1990 IPCC and the 1992 update, as reviewed in Section 13.6. For countries in sub-Saharan Africa, the Middle East and North Africa, Eastern Europe, and Latin America, however, there are still relatively few studies. For most regions, studies have focused on one or two principal grains. These studies strongly demonstrate the variability in estimated yield impacts among countries, scenarios, methods of analysis, and crops, making it difficult to generalize results across areas or for different climate scenarios. Thus, the ability to extend, interpolate, or extrapolate from the specific climate scenarios used in these studies to "more" or "less" climate change is limited.

Given these uncertainties in both magnitude and direction of impact, a key issue is *vulnerability* to possible climate change. Vulnerability is used here to mean the *potential* for negative consequences that are difficult to ameliorate through adaptive measures given the range of possible climate changes that might reasonably occur. Defining an area or population as vulnerable,

Table 13-11: Selected U.S. agricultural impact studies.

Study	Scenario	Geographic Scope	Crops	Yield Impact (%)	Other Comments
Adams *et al.*, 1988, 1990, 1994	GCMs[1]	U.S.	All	increase and decrease	Results vary across GISS, GFDL, and UKMO climates and regions; generally positive for 2°C and negative for 4°C; net economic effects depend on exports and CO_2 effects; increased irrigation; adaptation mitigates losses
Cooter, 1990	GISS	South	Maize	decrease	Potential risk of aquifer contamination
Easterling *et al.*, 1993	1930s analog	Missouri, Iowa, Nebraska, Kansas	Maize Sorghum Wheat Soybean Alfalfa	-23 to -6 -20 to +26 -11 to +17 -26 to +2 -5 to +22	More severe effect w/o CO_2 or adaptation; less severe or increase w/ CO_2 and adaptation
Kaiser *et al.*, 1993, 1994	Mild, severe	Central and southeast states, Minnesota, Nebraska	Maize Wheat Sorghum Soybean	increase and decrease	Climate scenarios included +2.5°C/+10% precipitation and +4.2°C/+20% precipitation; economic adaptation included; northern states less affected; results vary by crop/scenario
Mendelsohn *et al.*, 1994	+2.5°C, +8% precip.	U.S. county level	All	not estimated	Positive effect on crop revenue after long-run adjustment when considering revenue shares as weights that give greater importance to vegetables, fruits, etc.
Mearns *et al.*, 1992a, 1992b	GISS	Kansas	Wheat	increased variability and crop failure	Precipitation more important than temperature in scenarios, except for GISS
Muchow and Sinclair, 1991		Illinois	Grains	increase or slight decrease	Most sensitive to precipitation changes
Rosenzweig *et al.*, 1994	GISS, GFDL, UKMO*	Southeast U.S., Great Lakes U.S. sites	Soybean Maize Wheat	-96 to +58 -55 to +62 -100 to +180	w/ CO_2 effect; UKMO scenario, southern sites more severely affected; average for total USA assessed for wheat (-20 to -2%), maize (-30 to -15%), and soybeans (-40 to +15%); Peart *et al.* (1989), Ritchie *et al.* (1989), and Rosenzweig (1990) are similar studies

[1]These studies also considered yield sensitivity to +2 and +4°C and -20 and +20% change in precipitation.

therefore, is not a prediction of negative consequences of climate change; it is an indication that, across the range of possible climate changes, there are some climatic outcomes that would lead to relatively more serious consequences for the region than for other regions.

Vulnerability depends on the unit of observation and the geographic scale considered. *Yields* are relatively more vulnerable if a small change in climate results in a large change in yield. Evidence suggests that yields of crops grown at the margin of their climatic range or in climates where temperature or precipitation could easily exceed threshold values during critical crop growth periods are more vulnerable (e.g., rice sterility: Matthews *et al.*, 1994a, 1994b).

Farmer or farm sector vulnerability is measured in terms of impact on profitability or viability of the farming system. Farmers with limited financial resources and farming systems with few adaptive technological opportunities available to limit or reverse adverse climate change may suffer significant disruption and financial loss for relatively small changes in crop yields and productivity. For example, semi-arid, cool temperate, and cold agricultural areas may be more vulnerable to climate change and climate variability (Parry *et al.*, 1988).

Regional economic vulnerability reflects the sensitivity of the regional or national economy to farm sector impacts. A regional economy that offers only limited employment alternatives for workers dislocated by the changing profitability of farming is relatively more vulnerable than those that are economically diverse. For example, the Great Plains is one of the U.S. regions most dependent on agriculture, and thus might be the most economically vulnerable to climate change (Rosenberg, 1993).

Hunger vulnerability is an "aggregate measure of the factors that influence exposure to hunger and predisposition to its consequences" involving "interactions of climate change, resource constraints, population growth, and economic development" (Downing, 1992; Bohle *et al.*, 1994). Downing (1992) concluded that the semi-extensive farming zone, on the margin of more intensive land uses, appears to be particularly sensitive to small changes in climate. Socioeconomic groups in such areas, already vulnerable in terms of self-sufficiency and food security, could be further marginalized.

These different concepts of vulnerability include different scales of impact—from crop to individual farmer to food markets to the general economy. Given these various definitions and scales of impact, there are people vulnerable to climate change in most regions. Key characteristics of each of the regions help to suggest those more likely to have vulnerable populations (Table 13-13).

By most measures, many of the populations in sub-Saharan Africa appear most vulnerable. The region is already hot, and large areas are arid or semi-arid; average per capita income is among the lowest in the world and has been declining since 1980; more than 60% of the population depends directly on agriculture; and agriculture is generally more than 30% of gross domestic product (GDP). Relatively little of the cropland

Table 13-12: Selected Canadian agricultural impact studies.

Study	Scenario	Geographic Scope	Crop(s)	Yield Impact (%)	Other Comments
Williams *et al.*, 1988[1]	GISS84	Saskatchewan	Spring Wheat	-28 to -18	Large interannual fluctuations underlie mean impacts (e.g., -78% yield impact in extreme year); temperature increase of 3°C offset by +40% precipitation
Mooney, 1990[1]; Mooney *et al.*, 1991[1]	GISS	Manitoba, Alberta, Saskatchewan	Spring Wheat, Multiple Crops	-36 (Manitoba) negative and positive	Similar for other crops; corn and potatoes increased; precipitation derived from analogous region data; greater crop variety, production area increase
van Kooten[1]	CCC	SW Saskatchewan	Spring Wheat	-15 to +2	Positive effects when CCC precipitation used; negative used current norm for precipitation
Arthur and Abizadeh, 1989[1]	GISS, GFDL	Alberta, Manitoba, Saskatchewan	Wheat, Oats, Barley, Flax, Canola, Hay	small decrease to +28	10 out of 12 scenarios resulted in gain in net crop revenue; adapt by planting earlier
Brklacich *et al.*, 1994; Brklacich and Smit, 1992	GISS, GFDL, UKMO[2]	Alberta, Manitoba, Saskatchewan, Ontario	Wheat	-40 to +234	Results varied widely by site and scenario; adaptation and CO_2 were strongly positive effects; Ontario study showed increased net returns, but also variability; N gains and S loses

[1]As reported in Cohen *et al.*, 1992.
[2]These studies also considered yield sensitivity to +2 and +4°C and -20 and +20% change in precipitation.

is irrigated, and much of the agricultural land is used for grazing. Severe famine and starvation have been more prevalent in sub-Saharan Africa than in other regions over recent decades. Political and civil instability have greatly worsened problems. The potential for continued instability is an additional factor that increases vulnerability.

Populations in South Asia are vulnerable because of heavy dependence on agriculture and high population density. Agriculture accounts for more than 30% of GDP in most countries in the region. Each hectare of cropland supports 5.4 people. Tropical storms are an important feature of the climate around which current systems operate. These storms can be destructive but also are the main source of moisture. Changes in their frequency or severity would have significant impacts. The area is already intensely cropped, with 44% of the land area used as cropland. An estimated 31% of cropland is already irrigated, which may reduce vulnerability somewhat, providing water resources remain adequate. An additional factor that may reduce vulnerability in the future is the relative strength of the economy over the past decade. Countries in this area also have been relatively successful in avoiding the more severe effects of food shortages through programs that ensure access to food during potential famine situations. Chronic hunger remains a problem, however, for the poorer segments of the population, particularly in semi-arid and arid parts of the region.

Within East Asia, populations in the more arid areas of China appear most vulnerable to the possibility of mid-latitude continental drying. In general, the region supports a large population

***Table 13-13:** Basic regional agricultural indicators.*

	Sub-Saharan Africa	Middle East/ N. Africa	South Asia	SE Asia	East Asia	Oceania	Former USSR	Europe	Latin America	USA, Canada
Agric. Land (%)[1]	41	27	55	36	51	57	27	47	36	27
Cropland (%)[1]	7	7	44	13	11	6	10	29	7	13
Irrigated (%)[1]	5	21	31	21	11	4	9	12	10	8
Land Area (10^6ha)	2390	1167	478	615	993	845	2227	473	2052	1839
Climate	tropical, arid, humid	subtropical, tropical; arid	tropical, subtropical; humid, and	tropical; humid	subtropical, temp. oceanic, continental; humid	tropical, temp. oceanic, subtropical; arid, humid	polar, continental, temp. oceanic; humid, and	temp. oceanic, some sub-tropical, humid, and	tropical, subtropical; mostly humid	continental, subtropical, polar, temp. oceanic; humid, and
Pop. (10^6)	566	287	1145	451	1333	27	289	510	447	277
Agric. Pop. (%)	62	32	63	49	59	17	13	8	27	3
Pop/ha Cropland	3.6	3.4	5.4	5.7	12.6	0.5	1.3	3.7	2.9	1.2
Agric. Prod. (10^6t)										
Cereals	57	79	258	130	433	24	180	255	111	388
Roots and Tubers	111	12.5	26	50	159	3	65	79	45	22
Pulses	5.7	4.1	14.4	2.5	6.3	2	6	7	5.8	2.2
S. Cane and Beet	60	39	297	181	103	32	62	144	494	56
Meat	6.7	5.5	5.7	6.4	39.6	4.5	17	42	20.5	33.5
GNP/Cap.[2]	350	1940	320	930	590	13780	2700	15300	2390	22100
Annual Growth[2]	-1.2	-2.4	3.1	3.9	7.1	1.5	N/A	2.2	-0.3	1.7
Ag. (% of GDP)[2]	>30	10–19	>30	20–>30	20–29	<6	10–29	<6	10–19	<6

[1]Agricultural land includes grazing and cropland, reported as a percent of total land area. Cropland is reported as a percent of agricultural land. Irrigated area is reported as a percent of cropland.
[2]GNP is in 1991 U.S.$; annual growth (%/annum) is for the period 1980–1991.

Source: Computed from data from FAO Statistics Division (1992); GNP per capita, GNP growth rates, and agriculture as a share of the economy are from World Bank, *World Development Indicators 1993*, and temperature and climate classes from Rötter *et al.*, 1995. Note: East Asia GNP excludes Japan. Also, regional GNP data generally include only those countries for which data are given in Table 1 in *World Development Indicators*. Countries with more than 4 million population for which GNP data are not available include Vietnam, Democratic Republic of Korea, Afghanistan, Cuba, Iraq, Myanmar, Cambodia, Zaire, Somalia, Libya, and Angola; land areas are in hectares, production is in metric tonnes.

per hectare of cropland (12.6). The rapid economic growth achieved over the past decade, the fact that the region's climate is somewhat cooler, and the diverse sources of food production reduce vulnerability of populations in this region. Japan's GNP provides it with significant capability to limit climatic losses from agriculture compared with other countries in the region.

Southeast Asia combines tropical temperatures with generally ample moisture, but the region is subject to tropical storms. The region supports a large population with a relatively high population density per hectare of cultivated land. For several countries in this region, agriculture contributes more than 30% of GDP. GNP per capita is somewhat higher than that of either South or East Asia, and growth has been substantial over the past decade. However, Table 13-13 excludes several countries in the region due to lack of data. These countries, including Vietnam, Cambodia, and Myanmar, have relatively large populations, and their economic performance has been poorer than others in the region. Populations in these countries may be particularly vulnerable to changes in tropical storms.

The Middle East and North Africa are already very hot and generally arid. The current climate greatly limits the portion of land currently suitable for agriculture. A large share of current cropland is irrigated. Among developing country areas, a relatively smaller share of the population (32%) depends directly on agriculture. Agriculture is quite diverse; fruits, vegetables, and other specialty crops are important. The region is heterogeneous, including relatively wealthy oil-exporting countries, Israel, and several poorer countries—making the regional average economic performance somewhat misleading. Per capita GNP has fallen substantially over the past decade, with declining oil prices and political disruptions partly responsible.

Latin America and countries that now make up the area that was formerly the USSR are similar in terms of per capita GNP. While data are unavailable with regard to economic performance for the area of the former USSR, evidence strongly suggests that the region suffered a decline in per capita GNP over the past decade, as has Latin America. The two regions are also similar in that average population density and population per hectare of cropland are moderate to low. Estimates of potential additional cropland for the world suggest that these two areas could be the source of substantial additional cropland (Crosson, 1995). Thus, expansion of land area or relocation to adapt to climate change is a possible response, partly mitigating vulnerability. The prevalence of childhood malnutrition, infant mortality, and low median age at death are somewhat higher in Latin America than in the area of the former USSR (World Bank, 1993). While both regions are primarily humid, substantial agricultural areas are arid or semiarid and drought-prone. The notable difference between the two regions is that Latin America is generally already tropical or subtropical, and even though GCMs predict less warming in the tropics, further warming may be deleterious. In contrast, agriculture in large areas of the former USSR is limited by cool temperatures and so may benefit from warming. Arid areas of tropical Latin America, such as northwest Brazil, are particularly vulnerable to changes in ENSO events if they result in less reliable precipitation.

Europe, the USA and Canada, and Oceania have high GNP per capita, the agricultural population is a small share of the total population, and agriculture is in general a small share of the economy. As a result, vulnerability to climate-change-induced hunger or severe economic distress for the overall economy is relatively low. These areas are important for world food production. Mid-continental areas of the U.S. and Canada, the Mediterranean area of Europe, and large areas of Australia are prone to drought, which would be exacerbated if climate change reduced moisture availability or increased the demand for water as occurs in several GCM scenarios. Economic dislocation is likely to be limited to the agricultural sector or to subregions highly dependent on agriculture.

Small island nations, especially where incomes are low, are subject to particular vulnerabilities. Potential loss of coastal land to sea level rise, salt water intrusion into water supplies, damage from tropical storms, and temperature and precipitation change will combine to affect the agriculture of island nations. Sea water inundation and salt water intrusion are not unique to small island nations. However, these problems take on greater importance where coastal area is a high proportion of the total area of the country, alternative sources of fresh water are limited, and the area available for retreat from sea-level rise is limited. Local sources of food are especially important for these countries because transportation costs can be substantial for remote locations with small populations, particularly for highly perishable products. Most attention has been focused on Pacific Island Countries in Oceania, but other island countries such as the Maldives are presented with similar conditions.

13.8. Global Agricultural Issues and Assessments

13.8.1. The Current and Future Agricultural System

Climate change will be only one of many factors that will affect world agriculture. The broader impacts of climate change on world markets, on hunger, and on resource degradation will depend on how agriculture meets the demands of a growing population and threats of further resource degradation. World agriculture has proven in the past to be responsive to the increasing demand for food. Evidence of this is the trend of falling real prices for food commodities (Mitchell and Ingco, 1995, estimated a 78% decline between 1950 and 1992) and the steady growth of worldwide food production over the past 3 decades. Average annual increases were 2.7% per annum during the 1960s, 2.8% during the 1970s, and 2.1% during the 1980s.

Despite global abundance, many countries suffer from disrupted agricultural production and distribution systems, such that famine and chronic hunger are a reality or a distinct threat. While the number of people suffering from chronic hunger has declined (from an estimated 844 million in 1979 to 786 million in 1990; Bongaarts, 1994), the causes of famine are complex, including a lack of the rights and means to obtain food (employment, adequate income, and a public system for responding to famine) (e.g., Sen, 1981, 1993); political systems disrupted by war and unrest; ineffective or misdirected policies; as well as, or in addition to, drought and other extreme climatic events (McGregor, 1994). The nearly 800 million people still estimated to suffer from chronic hunger and malnutrition represent 20% of the population of developing countries, with the percentage as high as 37% in sub-Saharan countries (FAO, 1995). In many situations of chronic hunger, the population is rural and their livelihood depends primarily on agriculture. However, Kates and Chen (1994a, 1994b), though noting the potential risks of climate change beyond those represented in median cases, provide an array of actions that could be undertaken to achieve a food-secure world.

Agricultural and resource policies have important effects on agricultural production, and national governments have intervened in agriculture in many ways and for various reasons (Hayami and Ruttan, 1985). Many developed countries have subsidized agriculture and thereby encouraged production, while intentionally idling land to control surplus stocks of agricultural commodities. Many developing countries have controlled food prices to benefit lower-income food consumers but have thereby discouraged domestic production. Reduction of trade-distorting government interventions in agriculture was part of the recently concluded round of the General Agreement on Tariffs and Trade (GATT). National policies also greatly affect land use and water use, management, and pricing.

Three major studies of the future world food situation suggest that in the absence of climate change, food supply will continue to expand faster than demand over the next 20 to 30 years, with world prices projected to fall (Alexandratos, 1995; Mitchell and Ingco, 1995; Rosegrant and Agcaoili, 1995). Others are less optimistic, citing limits on further land expansion and irrigation, resource degradation, and reduced confidence that the historical rates of increase in yield will continue (Bongaarts, 1994; McCalla, 1994; Norse, 1994).

Factors that will jointly determine whether agricultural supply increases can keep pace with demand include (1) how fast demand will grow, (2) the future availability of land and its quality, (3) the future availability of water, and (4) whether improvements in technology will continue to result in rapid yield growth. Finally, economic growth and development are closely tied to demand growth and, in many developing countries, are also dependent on agricultural development.

13.8.1.1. Demand Growth

Between 1950 and 1990, world population grew at a 2.25% compound annual rate. Through 2025, population is projected to grow at a compound annual rate of between 1.13% and 1.55% (high and low UN variants). The decade of the 1990s is projected to have the largest absolute population addition, with declining additions in subsequent decades (Bongaarts, 1995). Thus, food supply growth could slow by 40–50% from recent decades while maintaining per capita food production levels. Income growth likely will cause demand to grow more rapidly than population and will change the composition of demand, most likely away from food grains and toward meat, fruits, and vegetables. The shift to meat is likely to increase the demand for grain for livestock feed. Increased demand generated by increased income growth would allow more and higher-quality food to be consumed per capita (Mitchell and Ingco, 1995), but this depends on how food consumption is distributed. Beyond 2025, population growth is generally projected to be low as world population is projected to stabilize by around 2075.

13.8.1.2. Land Quantity and Quality

Some estimates suggest that there is much potentially available land (Buringh and Dudal, 1987), but the cost of bringing it under production may be high, with attendant adverse environmental impacts limiting expansion (Crosson, 1995). Intensification of production on existing cropland may worsen land degradation and put additional pressure on water and soil resources. Firm data on the extent and severity of land degradation and its impact on production potential for most of the world are not available (El-Swaify *et al.*, 1982; Dregne, 1988; Nelson, 1988; Lal and Okigbo, 1990), but a recent overview (Oldeman et al., 1990), though still qualitative in economic terms, confirms significant degradation and loss of arable land, especially in Africa (see Chapter 4). Studies disagree on the extent to which intensification affects land degradation (Crosson and Stout, 1983; Brown and Thomas, 1990; Tiffen *et al.*, 1993). Competition for agricultural resources for other uses may also affect the supply and price of land for agriculture. Carbon sequestration, biomass energy production, forest product production, the potential development of new non-food agricultural products, and removal of agricultural land from production for other environmental objectives will affect the amount of land available for food production (see Chapters 23, 24, and 25).

13.8.1.3. Water Supply and Irrigation

Irrigation has contributed significantly to increased production in the past. Currently, 17% of global cropland is irrigated, but this 17% of land accounts for more than one-third of total world food production. An estimated additional 137 million hectares have the potential to be irrigated, compared with the 253 million hectares currently irrigated (World Bank, 1990), but the cost of doing so may be prohibitive. Current water systems in many developing countries achieve low efficiencies of water distribution, and average crop yields are well below potential (Yudelman, 1993; Crosson, 1995; Rosegrant and Agcaoili, 1995). There are environmental and health-related effects of irrigation such as soil salinization and the spread of water-borne diseases that may limit further expansion (Brown and Thomas, 1990, Dregne and Chou, 1990; Jensen *et al.*, 1990; Crosson, 1995). Major factors contributing to these irrigation problems in both developing and developed countries are unpriced and heavily subsidized water resources; inadequate planning, construction, and maintenance of water systems; unassigned water rights or rules that limit the transfer of rights; and conflicts between development and distribution goals (Frederick, 1986; Asian Development Bank, 1991; Moore, 1991; Umali, 1993; Yudelman, 1993; Appendine and Liverman, 1994). Solutions to these problems are available in most cases, and a recent study found that investments in irrigation have been at least as profitable as investments in other agricultural enterprises (World Bank, 1994). Changes in potential irrigation water supply due to climate change have not generally been integrated into agricultural impact studies, with few exceptions (e.g., Rosenberg, 1993). For climatic impacts on water supply, see Chapter 10.

13.8.1.4. Future Yield Growth

Assumed continuation of yield increases due to improving technology and further adoption of existing technologies is uncertain. Gaps between actual and potential yield are cited as evidence of unexploited production potential, but potential yields are rarely, if ever, attained in practice (Tinker, 1985; Plucknett, 1995). Realization of improved varieties depends on continuation of agricultural research and crop breeding systems and the exchange of germplasm (Duvick, 1995).

13.8.1.5. Future Economic Development

The impact of climate change on human populations in terms of famine, chronic hunger, health, and nutrition will depend on how and whether currently poor areas develop over the next 20 to 50 years. The future path of development of currently vulnerable countries remains uncertain. Policy failures, wars, and political and civil unrest are identified causes, but correcting these problems has proved difficult (e.g., van Dijk, 1992; Anand and Ravallion, 1993). Lagging agricultural development has been identified as a consequence of significant policy distortions in many developing countries, conflicting with the industrial sector and limiting the ability of the broader economy to grow (Hayami and Ruttan, 1985; Adelman and Vogel, 1992; Cavallo *et al.*, 1992; FAO, 1995).

13.8.2. Global Climate Impact Studies

Accurate consideration of national and local food supply and economic effects depends on an appraisal of changes in global food supply and prices. International markets can moderate or reinforce local and national changes. In 1988, for example, drought presented a more severe threat because it occurred coincidentally in several of the major grain-growing regions of the world.

While uncertainties continue to exist about the direction of change in global agricultural production resulting from climate change, changes in the aggregate level of production have been found to be small to moderate (Kane *et al.*, 1992; Fischer *et al.*, 1994; Reilly *et al.*, 1994; Rosenzweig and Parry, 1994). Studies show that a disparity in agricultural impact between developed and developing countries can be reinforced by markets (Tables 13-14, 13-15).

Rosenzweig *et al.* (1994) found that in lower-latitude developing countries, cereal grain crop yields and production declined under climate change scenarios ranging from 2.5 to 5.2°C. The study further found that the population at risk of hunger (defined as a measure of food energy availability, which depends on income and food price levels, relative to nutritional requirements) could increase despite adaptation. The study involved agricultural scientists in 18 countries using comparable crop growth models for wheat, rice, maize, and soybean (IBSNAT, 1989) and consistent climate change scenarios (Rosenzweig and Iglesias, 1994). Estimated yield changes were the basis for supply changes in the Basic Linked System (BLS), a world food trade model (Fischer *et al.*, 1988).

Reilly and Hohman (1993) and Reilly *et al.* (1994) used the same national crop yield changes as Rosenzweig *et al.* (1994) in a different trade model and found that agricultural exporters may gain even though their supplies fall as a result of higher world prices. They found that developing countries did worse in economic

Table 13-14: Change in cereals production under three different GCM equilibrium scenarios (percent from base estimated in 2060).

Region	GISS	GFDL	UKMO
World Total			
Climate effects only	-10.9	-12.1	-19.6
Plus physiological effect of CO_2	-1.2	-2.8	-7.6
Plus adaptation level 1	0.0	-1.6	-5.2
Plus adaptation level 2	1.1	-0.1	-2.4
Developed Countries			
Climate effects only	-3.9	-10.1	-23.9
Plus physiological effect of CO_2	11.3	5.2	-3.6
Plus adaptation level 1	14.2	7.9	3.8
Plus adaptation level 2	11.0	3.0	1.8
Developing Countries			
Climate effects only	-16.2	-13.7	-16.3
Plus physiological effect of CO_2	-11.0	-9.2	-10.9
Plus adaptation level 1	-11.2	-9.2	-12.5
Plus adaptation level 2	-6.6	-5.6	-5.8

Source: Rosenzweig and Parry, 1994.
Notes: Level 1 adaptation included changes in crop variety but not the crop, the planting date of less than 1 month, and the amount of water applied for areas already irrigated
Level 2 adaptation additionally included changes in the type of crop grown, changes in fertilizer use, changes in the planting date of more than 1 month, and extension of irrigation to previously unirrigated areas.

Table 13-15: Economic effects of three GCM equilibrium scenarios (billions of 1989 U.S.$).

	With CO_2 and Adaptation			With CO_2, No Adaptation			No CO_2, No Adaptation		
Region\GCM	**GISS**	**GFDL**	**UKMO**	**GISS**	**GFDL**	**UKMO**	**GISS**	**GFDL**	**UKMO**
Developing									
<$500/Cap.	-0.2	-2.6	-14.6	-2.1	-5.3	-19.8	-56.7	-66.1	-121.1
$500–2000/Cap.	-0.4	-2.9	-10.7	-1.8	-5.1	-15.0	-26.2	-27.9	-48.1
>$2000/Cap.	-0.6	-0.5	-1.0	-0.8	-0.9	-0.3	-6.7	-4.4	-3.9
Eastern Europe	2.4	0.0	-4.9	1.9	-2.0	-11.0	-12.5	-28.9	-57.5
OECD	5.8	0.0	-6.5	2.7	-3.6	-15.1	-13.5	-21.5	-17.6
TOTAL	7.0	-6.1	-37.6	0.0	-17.0	-61.2	-115.5	-148.6	-248.1

Source: Reilly *et al.*, 1994.
Notes: Measured as annual loss or gain in consumer and producer surplus plus change in society's cost of agricultural policies. Columns may not sum to total due to independent rounding. Adaptation is level 1, as in Table 13-14.

terms as a group, but that some developing countries benefitted. The pattern of winners and losers varied among climate scenarios. Moreover, they found that food-importing countries were found, in some cases, to suffer economic loss because of higher world prices even if the country's crop production potential improved.

Table 13-14 also illustrates how trade and adaptation capability can interact. Developing countries' production levels fell more under adaptation level 1 (small changes in planting dates, changes in cultivars, and additional irrigation water for areas already irrigated) than with no adaptation because their estimated capability to adapt was less than in developed countries. Thus, cereal production in developing countries fell further as trade shifted toward developed-country exports at the expense of developing country production. At adaptation level 2 (substantial changes in planting dates, changes in crop, and extension of irrigation systems), this situation was reversed.

Another global modeling effort considered potential yield and distribution of crops based on a crop suitability index (Cramer and Solomon, 1993; Leemans and Solomon, 1993). Although considering only one climate scenario and omitting the effect of CO_2 fertilization, they found that high-latitude regions uniformly benefited from longer growing periods and increased productivity. Other regions either did not benefit significantly or lost productivity.

More recent work considering global agriculture under climate change found far greater potential for global agriculture to adapt to changing climate than earlier studies (Darwin *et al.*, 1995; reported in Reilly, 1995). This study estimated that climate change alone as represented by equivalent doubled-CO_2 climate scenarios of UKMO, GISS, GFDL, and OSU, without consideration of the direct effects of CO_2, would result in global production losses of less than 1% if no additional land area were devoted to agriculture. If new land area could be brought under cultivation, grain production was estimated to increase on the order of 1%.

13.9. Adaptation

Historically, farming systems have adapted to changing economic conditions, technology, and resource availabilities and have kept pace with a growing population (Rosenberg, 1982; CAST, 1992). Evidence exists that agricultural innovation responds to economic incentives such as factor prices and can relocate geographically (Hyami and Ruttan, 1985; CAST, 1992). A number of studies indicate that adaptation and adjustment will be important to limit losses or to take advantage of improving climatic conditions (e.g., National Academy of Sciences, 1991; Rosenberg, 1992; Rosenberg and Crosson, 1991; CAST, 1992; Mendelsohn *et al.*, 1994).

Despite the successful historical record, questions arise with regard to whether the rate of change of climate and required adaptation would add significantly to the disruption likely due to future changes in economic conditions, technology and resource availabilities (Gommes, 1993; Harvey, 1993; Kane and Reilly, 1993; Smit, 1993; Norse, 1994; Pittock, 1994; Reilly, 1994). If climate change is gradual, it may be a small factor that goes unnoticed by most farmers as they adjust to other more profound changes in agriculture stemming from new technology, increasing demand for food, and other environmental concerns such as pesticide use, water quality, and land preservation. However, some researchers see climate change as a significant addition to future stresses, where adapting to yet another stress such as climate change may be beyond the capability of the system. Part of the divergence in views may be due to different interpretations of adaptation, which include the prevention of loss, tolerating loss, or relocating to avoid loss (Smit, 1993). Moreover, while the technological potential to adapt may exist, the socioeconomic capability to adapt likely differs for different types of agricultural systems (Reilly and Hohmann, 1993).

13.9.1. The Technological Potential to Adapt

Nearly all agricultural impact studies conducted over the past 5 years have considered some technological options for adapting to climate change. Among those that offer promise are:

- **Seasonal Changes and Sowing Dates**—For frost-limited growing areas (i.e., temperate and cold areas), warming could extend the season, allowing planting of longer maturity annual varieties that achieve higher yields (e.g., Le Houerou, 1994; Rowntree, 1990). For short-season crops such as wheat, rice, barley, oats, and many vegetable crops, extension of the growing season may allow more crops per year, fall planting, or, where warming leads to regular summer highs above critical thresholds, a split season with a short summer fallow. For subtropical and tropical areas where growing season is limited by precipitation or where the cropping already occurs throughout the year, the ability to extend the growing season may be more limited and depends on how precipitation patterns change. A study for Thailand found yield losses in the warmer season partially offset by gains in the cooler season (Parry *et al.*, 1992).
- **Different Crop Variety or Species**—For most major crops, varieties exist with a wide range of maturities and climatic tolerances. For example, Matthews *et al.* (1994) identified wide genetic variability among rice varieties as a reasonably easy response to spikelet sterility in rice that occurred in simulations for South and Southeast Asia. Studies in Australia showed that responses to climate change are strongly cultivar-dependent (Wang *et al.*, 1992). Longer-season cultivars were shown to provide a steadier yield under more variable conditions (Connor and Wang, 1993). In general, such changes may lead to higher yields or may only partly offset losses in yields or profitability. Crop diversification in Canada (Cohen *et al.*, 1992) and in China (Hulme *et al.*, 1992) has been identified as an adaptive response.
- **New Crop Varieties**—The genetic base is broad for most crops but limited for some (e.g., kiwi fruit). A study by Easterling *et al.* (1993) explored how hypothetical new varieties would respond to climate change (also reported in McKenney *et al.*, 1992). Heat, drought, and pest resistance; salt tolerance; and general improvements in crop yield and quality would be beneficial (Smit, 1993). Genetic engineering and gene mapping offer the potential for introducing a wider range of traits. Difficulty in assuring that traits are efficaciously expressed in the full plant, consumer concerns, profitability, and regulatory hurdles have slowed the introduction of genetically engineered varieties compared with early estimates (Reilly, 1989; Caswell *et al.*, 1994).
- **Water Supply and Irrigation Systems**—Across studies, irrigated agriculture in general is less negatively affected than dryland agriculture, but adding irrigation is costly and subject to the availability of water supplies. Climate change will affect future water supplies (see Chapter 10). There is wide scope for enhancing irrigation efficiency through adoption of drip irrigation systems and other water-conserving technologies (FAO, 1989, 1990), but successful adoption will require substantial changes in how irrigation systems are managed and how water resources are priced. Because inadequate water systems are responsible for current problems of land degradation, and because competition for water is likely to increase, there likely will be a need for changes in the management and pricing of water regardless of whether and how climate changes (Vaux, 1990, 1991; World Bank, 1994). Tillage method and incorporation of crop residues are other means of increasing the useful water supply for cropping.
- **Other Inputs and Management Adjustments**—Added nitrogen and other fertilizers would likely be necessary to take full advantage of the CO_2 effect. Where high levels of nitrogen are applied, nitrogen not used by the crop may be leached into the groundwater, run off into surface water, or be released from the soil as nitrous oxide. Additional nitrogen in ground and surface water has been linked to health effects in humans and affects aquatic ecosystems. Studies also have considered a wider range of adjustments in tillage, grain drying, and other field operations (Kaiser *et al.*, 1993; Smit, 1993).
- **Tillage**—Minimum and reduced tillage technologies, in combination with planting of cover crops and green manure crops, offer substantial possibilities to reverse existing soil organic matter, soil erosion, and nutrient loss, and to combat potential further losses due to climate change (Rasmussen and Collins, 1991; Logan, 1991; Edwards *et al.*, 1992; Langdale *et al.*, 1992; Peterson *et al.*, 1993; Brinkman and Sombroek, 1993; see also Chapter 23). Reduced and minimum tillage techniques have spread widely in some countries but are more limited in other regions. There is considerable current interest in transferring these techniques to other regions (Cameron and Oram, 1994).
- **Improved Short-Term Climate Prediction**—Linking agricultural management to seasonal climate predictions (currently largely based on ENSO), where such predictions can be made with reliability, can allow management to adapt incrementally to climate change. Management/climate predictor links are an important and growing part of agricultural extension in both developed and developing countries (McKeon *et al.*, 1990, 1993; Nichols and Wong, 1990).

13.9.2. The Socioeconomic Capability to Adapt

While identifying many specific technological adaptation options, Smit (1993) concluded that necessary research on their cost and ease of adoption had not yet been conducted

One measure of the potential for adaptation is to consider the historical record on past speeds of adoption of new technologies (Table 13-16). Adoption of new or different technologies depends on many factors: economic incentives, varying resource and climatic conditions, the existence of other technologies (e.g., transportation systems and markets), the availability of information, and the remaining economic life of equipment and structures (e.g., dams and water supply systems).

Specific technologies only can provide a successful adaptive response if they are adopted in appropriate situations. A variety of issues has been considered, including land-use planning, watershed management, disaster vulnerability assessment, port and rail adequacy, trade policy, and the various programs countries use to encourage or control production, limit food prices, and manage resource inputs to agriculture (CAST, 1992; OTA, 1993; Smit, 1993; Reilly *et al.*, 1994; Singh, 1994). For example, studies suggest that current agricultural institutions and policies in the United States may discourage farm management adaptation strategies, such as altering crop mix, by supporting prices of crops not well-suited to a changing climate, providing disaster payments when crops fail, or prohibiting imports through import quotas (Lewandrowski and Brazee, 1993).

Existing gaps between best yields and the average farm yields remain unexplained, but many are due in part to socioeconomic considerations (Oram and Hojjati, 1995; Bumb, 1995); this adds considerable uncertainty to estimates of the potential for adaptation, particularly in developing countries. For example,

Table 13-16: Speed of adoption for major adaptation measures.

Adaptation	Adjustment Time (years)	Reference
Variety Adoption	3–14	Dalrymple, 1986; Griliches, 1957; Plucknett *et al.*, 1987; CIMMYT, 1991; Wang *et al.*, 1992
Dams and Irrigation	50–100	James and Lee, 1971; Howe, 1971
Variety Development	8–15	Plucknett *et al.*, 1987; Knudson, 1988
Tillage Systems	10–12	Hill *et al.*, 1994; Dickey *et al.*, 1987; Schertz, 1988
New Crop Adoption: Soybeans	15–30	FAO, Agrostat (various years)
Opening New Lands	3–10	Medvedev, 1987; Plusquellec, 1990
Irrigation Equipment	20–25	Turner and Anderson, 1980
Transportation System	3–5	World Bank, 1994
Fertilizer Adoption	10	Pieri, 1992; Thompson and Wan, 1992

Baethgen (1994) found that a better selection of wheat variety combined with an improved fertilizer regime could double yields achieved at a site in Uruguay to 6 T/ha under the current climate with current management practices. Under the UKMO climate scenario, yields fell to 5 T/ha—still well above 2.5–3.0 T/ha currently achieved by farmers in the area. On the other hand, Singh (1994) concludes that the normal need to plan for storms and extreme weather events in Pacific island nations creates significant resiliency. Whether technologies meet the self-described needs of peasant farmers is critical in their adaptation (Cáceres, 1993). Other studies document how individuals cope with environmental disasters, identifying how strongly political, economic, and ethnic factors interact to facilitate or prevent coping in cases ranging from the Dust Bowl disaster in the United States to floods in Bangladesh to famines in the Sudan, Ethiopia, and Mozambique (McGregor, 1994). These considerations indicate the need for local capability to develop and evaluate potential adaptations that fit changing conditions (COSEPUP, 1992). Important strategies for improving the ability of agriculture to respond to diverse demands and pressures, drawn from past efforts to transfer technology and provide assistance for agricultural development, include:

- Improved training and general education of populations dependent on agriculture, particularly in countries where education of rural workers is currently limited. Agronomic experts can provide guidance on possible strategies and technologies that may be effective. Farmers must evaluate and compare these options to find those appropriate to their needs and the circumstances of their farms.
- Identification of the present vulnerabilities of agricultural systems, causes of resource degradation, and existing systems that are resilient and sustainable. Strategies that are effective in dealing with current climate variability and resource degradation also are likely to increase resilience and adaptability to future climate change.
- Agricultural research centers and experiment stations can examine the "robustness" of present farming systems (i.e., their resilience to extremes of heat, cold, frost, water shortage, pest damage, and other factors) and test the robustness of new farming strategies as they are developed to meet changes in climate, technology, prices, costs, and other factors.
- Interactive communication that brings research results to farmers—and farmers' problems, perspectives, and successes to researchers—is an essential part of the agricultural research system.
- Agricultural research provides a foundation for adaptation. Genetic variability for most major crops is wide relative to projected climate change. Preservation and effective use of this genetic material would provide the basis for new variety development. Continually changing climate is likely to increase the value of networks of experiment stations that can share genetic material and research results.

- Food programs and other social security programs would provide insurance against local supply changes. International famine and hunger programs need to be considered with respect to their adequacy.
- Transportation, distribution, and market integration provide the infrastructure to supply food during crop shortfalls that might be induced in some regions because of climate variability or worsening of agricultural conditions.
- Existing policies may limit efficient response to climate change. Changes in policies such as crop subsidy schemes, land tenure systems, water pricing and allocation, and international trade barriers could increase the adaptive capability of agriculture.

Many of these strategies will be beneficial regardless of how or whether climate changes. Goals and objectives among countries and farmers vary considerably. Current climate conditions and likely future climates also vary. Building the capability to detect change and evaluate possible responses is fundamental to successful adaptation.

13.10. Research Needs

The continuing uncertainty in projections suggests three critical, high-priority research needs:

- Development and broad application of integrated agricultural modeling efforts and modeling approaches particularly applicable at the regional scale, including increased attention to validation, testing, and comparison of alternative approaches. Climate effects on soils and plant pests, consideration of other environmental changes, and adaptation options and economic responses should be an integrated part of the models rather than treated on an *ad hoc* basis or as a separate modeling exercise. Inclusion of these multiple, joint effects may significantly change our "mean" estimate of impact, and more careful attention to scale and validation should help to reduce the range of estimates for specific regions and countries across different methodologies.
- Development of the capability to readily simulate agricultural impacts of multiple transient climate scenarios. Study of the sensitivities of agriculture to climate change and the impacts of doubled-CO_2 equilibrium scenarios has not led to the development of methods that readily can be applied to transient climate scenarios. To deal credibly with the cost of adjustment, about which there is significant uncertainty, the process of socioeconomic adjustment must be modeled to treat key dynamic issues such as how the expectations of farmers change, whether farmers can easily detect climate change against a background of high natural variability, and how current investments in equipment, education, and training may lead to a system that only slowly adjusts, or adjusts only with high cost and significant disruption. The ability to readily simulate effects under multiple climate scenarios is necessary to quantify the range of uncertainty.
- Evaluation of the effects of variability rather than changes in the "mean" climate, and the implication of changes in variability on crop yields and markets. Extreme events have severe effects on crops, livestock, soil processes, and pests. The more serious human consequences of climate change also are likely to involve extreme events such as drought, flooding, or storms, where agricultural production is severely affected.

State-of-the-art research has begun addressing these areas, and a number of promising approaches have begun to appear in the literature or are expected soon. Most are, as yet, "demonstration" research projects, choosing limited geographic areas where data are more available and considering convenient examples for climate scenarios. Caution in drawing broader policy implications from such studies is warranted because there is little or no basis to make inferences to broader populations, to other locations, or to specific climate scenarios.

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Climate Change 1995

Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses

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Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change

Published for the Intergovernmental Panel on Climate Change

CAMBRIDGE
UNIVERSITY PRESS

Letters Signed by Thousands of Scientists Urging Action

Q14. On page 9 of your written testimony you also state that "The Administration has received letters signed by thousands of scientists in the last few months urging action on this issue -- warning that nonlinearities or unexpected events, such as the Antarctic ozone hole, are more likely when rates of change are very fast."

Please document this statement.

A14. Attached are: (1) a copy of the Scientists Statement on Global Climatic Disruption, signed by 2,600 scientists; (2) a list of the signatories for item 1; and (3) a copy of the World Scientists Call for Action at the Kyoto Summit, signed by more than 1500 scientists, including 104 Nobel Laureates.

Scientists' Statement
Global Climatic Disruption
June 18, 1997

We are scientists who are familiar with the causes and effects of climatic change as summarized recently by the Intergovernmental Panel on Climate Change (IPCC). We endorse those reports and observe that the further accumulation of greenhouse gases commits the earth irreversibly to further global climatic change and consequent ecological, economic and social disruption. The risks associated with such changes justify preventive action through reductions in emissions of greenhouse gases. In ratifying the Framework Convention on Climate Change, the United States agreed in principle to reduce its emissions. It is time for the United States, as the largest emitter of greenhouse gases, to fulfill this commitment and demonstrate leadership in a global effort.

Human-induced global climatic change is under way. The IPCC concluded that global mean surface air temperature has increased by between about 0.5 and 1.1 degrees Fahrenheit in the last 100 years and anticipates a further continuing rise of 1.8 to 6.3 degrees Fahrenheit during the next century. Sea-level has risen on average 4-10 inches during the past 100 years and is expected to rise another 6 inches to 3 feet by 2100. Global warming from the increase in heat-trapping gases in the atmosphere causes an amplified hydrological cycle resulting in increased precipitation and flooding in some regions and more severe aridity in other areas. The IPCC concluded that "The balance of evidence suggests a discernible human influence on global climate." The warming is expected to expand the geographical ranges of malaria and dengue fever and to open large new areas to other human diseases and plant and animal pests. Effects of the disruption of climate are sufficiently complicated that it is appropiate to assume there will be effects not now anticipated.

Our familiarity with the scale, severity, and costs to human welfare of the disruptions that the climatic changes threaten leads us to introduce this note of urgency and to call for early domestic action to reduce U.S. emissions via the most cost-effective means. We encourage other nations to join in similar actions with the purpose of producing a substantial and progressive global reduction in greenhouse gas emissions beginning immediately. We call attention to the fact that there are financial as well as environmental advantages to reducing emissions. More than 2000 economists recently observed that there are many potential policies to reduce greenhouse-gas emissions for which total benefits outweigh the total costs.

The Framework Convention on Climate Change, ratified by the United States and more than 165 other nations, calls for stabilization of greenhouse gas concentrations in the atmosphere at levels that will protect human interests and nature. The Parties to the Convention will meet in December, 1997, in Kyoto, Japan to prepare a protocol implementing the convention. We urge that the United States enter that meeting with a clear national plan to limit emissions, and a recommendation as to how the U.S. will assist other nations in significant steps toward achieving the joint purpose of stabilization.

Initial Signatories

Dr. John P. Holdren	Dr. Peter H. Raven
Dr. Jane Lubchenco	Dr. F. Sherwood Rowland
Dr. Harold A. Mooney	Dr. George M. Woodwell

Signed by 2409 scientists as of 6:19 PM on June 17, 1997

Ozone Action 1636 Connecticut Avenue, NW Washington, DC 20009 Voice: (202) 265-6738 FAX: (202) 986-6041

Scientists' Statement on Global Climatic Disruption

June 1997

"More than 2,400 scientists, including most of the nation's experts on climate change, have called on the Clinton Administration to take 'early domestic action' to reduce... global warming."

- Wall Street Journal, June 19, 1997

Initial Signatories:

John P. Holdren

Jane Lubchenco

Harold A. Mooney

Peter H. Raven

F. Sherwood Rowland

George M. Woodwell

Scientists' Statement
Global Climatic Disruption
June 18, 1997

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Dr. Jane Lubchenco	Dr. F. Sherwood Rowland
Dr. Harold A. Mooney	Dr. George M. Woodwell

Endorsed by over 2,600 Scientists

Ozone Action 1636 Connecticut Avenue, NW Washington, DC 20009 Voice: (202) 265-6738 FAX: (202) 986-6041

July 28, 1997

In the pages that follow are the names of over 2,600 scientists who have joined in calling upon the United States to take global leadership in reducing emissions of the heat-trapping gases that are causing global climatic disruption. The principal gas is carbon dioxide from burning oil, gas and coal.

Scientists do not often join in calling for governmental leadership on environmental questions of global concern. In this instance, they have the detailed background of a century of careful study capped by two recent reviews of the issue by more than 2,000 scientists from around the world who worked under the auspices of the Intergovernmental Panel on Climate Change. The product is the most comprehensive study of a global environmental issue ever produced, as important as the studies of nuclear weapons and the hazards of radioactivity of earlier years.

The scientists who signed the statement are all experts with broad experience in addressing various aspects of the disruptions of climate. Thirty-six of the signatories are members of the National Academy of Sciences. Three are Nobel Laureates. They range in specialties from physical chemistry and biochemistry though oceanography and climatology to geography and ecology. They are college presidents, advisors to governments, members of governmental staffs, and scientific participants in the private sector. They are advisors to President Clinton and researchers from private laboratories. They are textbook authors and a former Secretary of the Smithsonian, conservationists, landowners, reclusive academicians, and active publicists of science. They are citizens, native born and immigrant, they are from every ethnic group. But above all, they are seriously concerned that failure of the United States to act now will be a very costly error for us, and our children.

Please read the statement carefully. It calls for a bold new departure on the part of the United States.....now.

Yours truly,

George M. Woodwell
Initial Signatory
Director, The Woods Hole Research Center
Woods Hole, Massachusetts

John Passacantando
Executive Director
Ozone Action
Washington, D.C.

Signatories to the Scientists' Statement - NAS Members

These institutions are listed for identification purposes only They do not represent the endorsement of the institution listed

Number of contacts: 36

Signatory	Degree	Institutional Affiliation
Robert McCormick Adams	PhD	+ University of California - San Diego
Wyatt W Anderson	PhD	+ University of Georgia
John Tyler Bonner	PhD	+ Princeton University
Theodore H Bullock	PhD	+ University of California at San Diego
John Cairns, Jr.	PhD	+ Virginia Polytechnic Institute & State Univ
G Brent Dalrymple	PhD	+ Oregon State University
Margaret Bryan Davis	PhD	+ University of Minnesota
Dr Jared M. Diamond	PhD	+ UCLA School of Medicine
W T Edmondson	PhD	+ University of Washington
Paul R Ehrlich	PhD	+ Stanford University
Thomas Eisner	PhD	+ Cornell University
W G Ernst	PhD	+ Stanford University
Melvin M Grumbach	MD	+ University of California, San Francisco
Robert A Hellwell	PhD	+ Stanford University
Ernest M Henley	PhD	+ University of Washington
John P Holdren	PhD	+ Harvard University
Holger Jannasch	PhD	+ Woods Hole Oceanographic Institution
Henry W Kendall	PhD	+ Massachusetts Institute of Technology
Donald Kennedy	PhD	+ Stanford University
Arthur H Lachenbruch	PhD	+ U S Geological Survey
Estella B Leopold	PhD	+ University of Washington
Gene E Likens	PhD	+ Institute of Ecosystem Studies
Jane Lubchenco	PhD	+ Oregon State University
Jerrold Meinwald	PhD	+ Cornell University
Charles D Michener	PhD	+ University of Kansas
Mario J Molina	PhD	+ Massachusetts Institute of Technology
Harold A Mooney	PhD	+ Stanford University
Eugene P Odum	PhD	+ University of Georgia
Robert T Paine	PhD	+ University of Washington
Peter H Raven	PhD	+ Missouri Botanical Garden
Peter B Rhines	PhD	+ University of Washington
F Sherwood Rowland	PhD	+ University of California - Irvine
Andrew M Sessler	PhD	+ Lawrence Berkeley National Laboratory
John W Terbough	PhD	+ Duke University
Edward O Wilson	PhD	+ Harvard University
George M Woodwell	PhD	+ Woods Hole Research Center

Signatories to the Scientists' Statement - Alabama

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Number of contacts 33

Signatory	Degree	Institutional Affiliation
Michael Domingo Agbeti	PhD	Bio-Research and Consulting
Arthur C Benke	PhD	University of Alabama
Robert J Beyers	PhD	University of South Alabama
Jules Blais	PhD	University of Alberta
Jean-Claude J Bonzongo	PhD	The University of Alabama
James M Byrne	PhD	The University of Lethbridge
James Harley Cane	PhD	Auburn University
Arthur Chapella III	PhD	Auburn University
Da-Chang Chu	PhD	University of Alabama at Birmingham
Dennis DeVriess	PhD	Auburn University
William F Donahue	PhD (Candidate)	University of Alberta
Herdon G Dowling	PhD	Rendalia Biologists
John Christopher Earle	PhD	Corcordia University-College of Alberta
Everett Fee	PhD	University of Calgary
John C. Frandsen	PhD	Tuskegee University
Francesca Gross	MS	CH2M Hill
Bernhard Kaltenboeck	PhD	Auburn University
Ambre Kayser	MS (in progress)	Auburn University
Ronald P Kiene	PhD	University South Alabama
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Suzanne W Lindblom	MA	University of Alabama
Trisha May	PhD	University of Alabama
Candace McCombs	PhD	University of South Alabama
Anthony Moss	PhD	Auburn University
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Eric Eugene Rodan	PhD	The University of Alabama
Elizabeth B. Rodgers	PhD	NASA
Lisa J Samuelson	PhD	Auburn University
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Laurence G Tate	PhD	University of South Alabama
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Signatories to the Scientists' Statement - Alaska

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Number of contacts 21

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Vera Alexander	PhD	University of Alaska - Fairbanks
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Roman J. Dial	PhD	Alaska Pacific University
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Douglas L. Kane	PhD	University of Alaska, Fairbanks
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Robert Joseph Piorkowski	PhD	
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Bruce Wright	MS	University of Alaska Southeast
Shijie Zhou	PhD	Alaska Dept. of Fish and Game

Signatories to the Scientists' Statement - Arizona

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Number of contacts 36

Signatory	Degree	Institutional Affiliation
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May 21, 1997

President Bill Clinton
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Dear President Clinton:

Ecologists' Statement on the Consequences of Rapid Climatic Change

Climate change driven by emissions of greenhouse gases is projected to occur at a very rapid rate, significantly faster, on a sustained global basis, than rates of climatic change during the past 10,000 years (1). Rapid climate change coupled with pollution, habitat fragmentation and habitat loss may lead to the decline and disappearance of many plant and animal communities that might otherwise survive a future climate that is relatively stable but warmer.

We believe that this situation constitutes a dangerous anthropogenic interference with the climate system, one that may not "allow ecosystems to adapt naturally to climate change" as is called for in the Framework Convention on Climate Change (1992). Accordingly, we believe that the prudent course would be to limit climate change to the lowest rates feasible given emissions that have already occurred. These correspond to global rates of warming of no more than 1 degree C per century.

Much of the current debate over limiting global climate change has focused on targets for stabilization of greenhouse gas concentrations many decades in the future. However from an ecological standpoint, it is the *rapid rate* as well as the total magnitude of climate change projected to occur that is pertinent to the future well-being of plant and animal communities and to the continuous availability of goods and services they provide to our society. Global mean temperature could increase by as much as 1-3.5 degrees C (2-6 degrees F), over the next 100 years. At higher latitudes, which include large portions of the United States, temperature increases could be much greater.

Rapid climate change is more dangerous to plant and animal communities than gradual climate change even if the total amount of change that eventually occurs is exactly the same.

During rapid climate change, disturbances like fires, floods, erosion, droughts, storms, pests and pathogen outbreaks may increase with adverse effects on ecosystem functions as important as water supply, soil fertility and carbon sequestration. After disturbance, aggressive, 'weedy' species, including exotics that outcompete native vegetation, may come to dominate these areas. In some US temperate forests, rapid climate change could lead to widespread tree mortality, wildfires and replacement of the forests by grasslands. Species that are long-lived, rare, or endangered will be severely disadvantaged.

In an increasingly developed world, there are fewer and fewer areas available in which native trees and plants can grow. Cities, highways, agricultural fields and other human activities limit available habitat and create barriers to the migration of plants and animals. In fact, many natural areas now can be considered 'islands' in a sea of developed land. Protected areas like national parks and forests were established with current climates in mind. Rapid climate shifts may reduce appropriate native habitats within protected areas while development outside the boundaries of the protected areas would make much of the neighboring new habitat unavailable and limit corridors for species to migrate to suitable new habitats. It would be difficult to imagine, for example, how the imperiled species of Everglades National Park, such as the Cape Sable Sparrow and American Crocodile, could migrate north into the urban and agricultural landscapes of coastal and central Florida and successfully re-establish themselves. Overall, climate change, in combination with existing anthropogenic habitat disruption and loss, could lead to steep declines in worldwide biodiversity.

Furthermore, conditions for plant and animal communities are considerably less hospitable now than prior to the industrial revolution. In many cases, plant and animal populations are less healthy and ecosystems less resilient to further disturbance due to environmental stress from human-made pollutants and habitat degradation. These stresses may reduce significantly an individual's or ecosystem's ability to cope successfully with climate change.

Climate change may also result in rapid sea level rise. Rapid sea level rise causes beach erosion and threatens coastal marshes and mangrove forests. While many of these coastal natural areas have kept pace with historic rates of sea level rise, faster rates may lead to inundation of marshes and mangroves more rapidly than new wetlands can form. Onshore human development will further hamper new establishment of coastal natural areas. Loss of habitat for a substantial number of species of birds, fish, shellfish, microorganisms and animals could result. Marshes and mangroves also protect shorelines from storms and high tides and act as filters for pollutants such as sewage and other effluents. Their loss would lead to increased erosion and degradation of onshore human development.

It is difficult to quantify precisely the response of a particular species or group of species to climate change. Because there are only sparse records of this type of rapid climate change available, we have little to guide our estimations. Scientists do know the following. Climate determines the distributions of many species. Significant climate change has in the past and will in the future require many species to shift their ranges. Species vary in their ability and opportunities to adapt or migrate. The rate of projected change is enough to threaten seriously the survival of many species. Pollution and human alteration of the landscape have reduced considerably the ability of plant and animal communities to adjust to rapid climate change. Ecosystems will experience a rate of sustained climate change that is unusually rapid and, for many areas, unprecedented during the past 10,000 years. The more rapid that rate, the more vulnerable to damage ecosystems will be.

We are performing a global experiment on our natural ecosystems for which we have little information to guide us. While plant and animal communities may be able to eventually adapt to a stable climate system that is warmer than the existing one, many species may not be able to survive a rapid transition to that new climate. The prudent course would be to limit climate change to the lowest rates feasible given current atmospheric accumulations of greenhouse gases. These correspond to global rates of warming of no more than 1 degree C per century.

(1) *Climate Change 1995 - Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses.* Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change. Editors R.T. Watson, M.C. Zinyowera, R.H. Moss. Cambridge University Press, p. 21.

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<u>**Similar Letters Urging Action from the Economic Community**</u>

Q15. On page 10 of your written testimony you state that "We have received similar letters urging action from the economic community."

Please document this statement.

A15. Attached is a copy of the statement endorsed by over 2,000 economists.

Economists' Statement on Climate Change

Endorsed by Over 2000 Economists including six Nobel Laureates

I. The review conducted by a distinguished international panel of scientists under the auspices of the Intergovernmental Panel on Climate Change has determined that "the balance of evidence suggests a discernible human influence on global climate." As economists, we believe that global climate change carries with it significant environmental, economic, social, and geopolitical risks, and that preventive steps are justified.

II. Economic studies have found that there are many potential policies to reduce greenhouse-gas emissions for which the total benefits outweigh the total costs. For the United States in particular, sound economic analysis shows that there are policy options that would slow climate change without harming American living standards, and these measures may in fact improve U.S. productivity in the longer run.

III. The most efficient approach to slowing climate change is through market-based policies. In order for the world to achieve its climatic objectives at minimum cost, a cooperative approach among nations is required—such as an international emissions trading agreement. The United States and other nations can most efficiently implement their climate policies through market mechanisms, such as carbon taxes or the auction of emissions permits. The revenues generated from such policies can effectively be used to reduce the deficit or to lower existing taxes.

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Regional Vulnerabilities

Q16. On page 11 of your written testimony you state the following:

"Alaska: The state's economic dependence on natural resources makes it highly vulnerable to climate change. Global warming will be most pronounced in northern regions. Probable consequences include drying of Alaska's interior, inundation of fragile coastal delta areas, and, most seriously, melting of permafrost, which is already underway. Continuation of Alaskan warming will lead to the disappearance of most discontinuous permafrost over the next 100 years. In many places, ground level can collapse 5 yards or more, leading to significant damages to ecosystems and human infrastructure. Houses, roads, airports, military installations, pipelines, and any other facility built on ice-rich permafrost are at risk. The melting of permafrost and the warming of tundra will lead to the release of carbon and methane deposits from the formerly frozen lands, which could make them an additional source of atmospheric greenhouse gases. Ecosystem effects include destruction of trees and caribou habitat; clogging of salmon spawning streams; reduction in forested areas; expansion of lakes and wetlands; and increased rates of coastal and riverbank erosion, slope instability, landslides and erosion."

Please document these statements.

A16. To improve understanding of the consequences of global change for the nation, the Office of Science and Technology Policy and the U.S. Global Change Research Program (USGCRP) are sponsoring a series of regional workshops throughout the country. The purpose of these workshops is to start the process of examining the vulnerabilities of regions of the U.S. to climate variability and climate change and to begin to aggregate information across the regions to support nation-scale assessment (called for in the Global Change Research Act). Workshop participants include the broad research and stakeholder community, drawn from federal, state, and local governments; universities and laboratories; industry, agricultural and natural resource managers; non-governmental organizations; and others. Eight workshops were held in 1997, and 12 additional workshops are planned for 1998, or have already been held earlier this year. Each workshop will ultimately produce a comprehensive workshop report, which will provide the regional perspective for the National Assessment, due to be completed by the end of 1999.

The statements concerning Alaska are based on discussions held at the workshop in Alaska, organized by the University of Alaska, Fairbanks, AK, held June 3 – 6, 1997. Several of the statements made are drawn from peer-reviewed literature. The fact that the highest latitudes will experience the most pronounced warming is documented in the IPCC Reports. Alaska is already experiencing warming and permafrost melting (Weller et al. 1995; Lachenbruch and Marshall 1986; Osterkamp 1994; Wadhams 1990; Chapman and Walsh 1993). The impacts of permafrost melting are extensive (Esch and Osterkamp, 1990; Osterkamp 1994; Osterkamp and Romanovsky 1996). Melting permafrost and warming of the tundra will lead to the further release of carbon dioxide and methane (e.g., Oeschel et al. 1995). Ecosystem effects will be wide ranging (e.g., Chapin et al. 1992; Cooch et al. 1991; Sedinger et al. 1993, Valkenberg 1991).

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Q17. On page 12 of your written testimony you state the following:

"Great Plains: All sectors of life in the Great Plains are dependent on a very limited water supply, and water shortages there are already a problem. The further drying expected from climate change poses the region's most significant risk. Agriculture is the base of the economy, despite the constraints of the dry and variable environment. Because agricultural water needs often exceed rainfall, water for irrigation is commonly supplied from deep aquifers, which are experiencing overdrafts and dropping water tables. As climate change leads to warmer conditions and an intensified hydrological system, the soils of the area are anticipated to further dry. The simultaneous drop in aquifer levels, greater run-off from extreme downpours, and shorter duration of snow cover will exacerbate the region's water supply problems. Drier soils could be subject to increased wind erosion, which has led to "dust bowl" conditions in the past. Better soil tillage practices would simultaneously improve soil fertility, soil carbon storage capacity, and soil moisture holding capacity. Native species will face increasing levels of competition from introduced species, such as cheat grass, Japanese brome, Russian thistle, and leafy spurge, which already account for extensive economic losses. Riparian areas (wetlands and prairie potholes), which are used intensively by hunters, anglers, and bird watchers, are extremely vulnerable to warmer, drier climate."

Please document these statements.

A17. As with the Alaska example (Q16), this example of regional vulnerability to climate change is based on the discussions from a workshop on the impacts of climate change. The Final Workshop Report has not yet been completed. The workshop on the Central Great Plains was held at Fort Collins, CO, May 27-29, 1997.

The statements regarding the dependence of the economic and social sectors of the Great Plains on the limited water supply are detailed in Duncan et al. (1995), Riebsame (1990), and Schimel et al. (1990). In the region, agricultural water needs often exceed rainfall (Opie 1996, OTA Report). The region's soils are anticipated to further dry, exacerbating the region's current water problems (Parton et al. 1994, Schimel et al. 1990). The fact that the native species of the region are facing increasing levels of competition from invasive non-native species is a widely accepted concept (e.g., see Mooney and Drake (1986) and the OTA Report on Non-indigenous species).

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Q18. On page 12 of your written testimony you also state the following:

"Southeast: The Southeast is a region of abundance, with numerous wetlands, an extensive coastline, and productive agriculture, fisheries, and forestry. Urbanization and rapid population growth are already exerting significant stress on some fragile ecosystems. The Florida Everglades have been significantly altered by human encroachment, with approximately half of the ecosystem lost or severely altered by drainage for development as well as pollution from agricultural run-off. While the Southeast's long coastline makes it a recreational playground, its low elevation renders it extremely vulnerable to sea level rise and storm surges during extreme weather events, such as hurricanes, which are expected to worsen with climate change. A 1 foot rise in sea-level, the best estimate over the next century, could erode 100 to 1000 feet of Florida beaches, damaging property as well as tourist interests."

Please document these statements.

A18. As with the Alaska example (Q16), this example of regional vulnerability to climate change is based on the discussions from a workshop on the impacts of climate change. The Final Workshop Report has not yet been completed. The workshop on the Southeast was held in Nashville, TN, June 25-27, 1997.

We assume that the request for documentation refers only to the assertions about climate change. The best documentation for the fact that Florida has low elevations would be the USGS topographic maps, which are available from USGS.

The point that higher sea level is expected to result in greater storm surges has been well established since Barth and Titus (1984) ("Greenhouse Effect and Sea Level Rise", Van Nostrand Reinhold). IPCC (1995) indicated that we do not yet know whether hurricane intensity will also strengthen. The 100-1000 foot erosion of Florida beaches is from the seminal paper by Per Bruun (1962) which first introduced what is now called "the Bruun Rule." Note, however, that studies cited in Titus et al, 1991 (Coastal Management, Volume 19, pages 171-204) found that erosion of 50-400 feet would be more typical along sandy beaches. On the other hand, shores could retreat a few miles in some wetland areas of Louisiana and Florida. (For a map of South Florida inundation, see http://www.erols.com/dickpark/SLAMM.htm.)

Q19. On pages 12 and 13 of your written testimony you state the following:

"Southwest: Rapid population growth in this arid or semi-arid region make the Southwest extremely vulnerable to water supply problems that are likely to worsen under climate change. The region is naturally subject to large climate fluctuations, which have produced fairly robust adaptation mechanisms in ranching and agriculture. The native flora and fauna are also well adapted to life in this harsh and dry environment. Surface water supplies are insufficient; forcing reliance on groundwater, use of which already exceeds recharge and is leading to subsidence in many areas. Climate change will pose serious challenges and is likely to result in significant impacts to the region's traditional economic sectors as well as tourism, development, and retail sectors that now make up much of the region's economy. Expected conditions include more extremely hot days, fewer cool days, and decreased winter precipitation. Alteration of the region's hydrologic cycle would affect quantity and quality of the water supply, with major implications for continued development in the region. Significant changes in vegetation are also predicted, with Gambel oak, Piñon pine, and Douglas fir largely disappearing from the region. Saguaro would die off in its current range, but might find a new home further east and at higher elevations."

Please document these statements.

A19. As with the Alaska example (Q16), this example of regional vulnerability to climate change is based on the discussions from a workshop on the impacts of climate change. The Final Workshop Report has not yet been completed. The workshop on the Southwest was held in Tucson, Arizona, September 3-5, 1997.

The Southwest is a semi-arid region currently vulnerable to water supply problems (Sellers and Hill 1974; Stromberg et al. 1996; Glennon and Maddock 1994). Population growth will further stress the limited water situation (Lord et al. 1991). Climate change is expected to worsen the situation in the region (Gleick et al. 1995; Morrison et al. 1996). Climate change and droughts will impact the region's economic sectors (Brown 1996; FAO 1996; Fohn 1996; NOAA report 1996). Expected conditions for the region include more hot days, and decreased winter precipitation (VEMAP, 1995). Significant changes in vegetation distribution are also likely (Thompson 1988; Thompson et al. 1998).

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Q20. On page 13 of your written testimony you state the following:

"New England: New England's economy is diverse, and many aspects are indirectly dependent on climate. Its natural areas are prized, and its fall foliage draws visitors from all over the world. The region is vulnerable to drought and severe storms, which modify its vegetation and impact production of forest and fisheries products. Warmer, drier climate could reduce ski tourism and shift optimal climatic conditions north into Canada for the tree species prized for their fall foliage and maple syrup. Coastal areas are likely to be affected by intensifying storms, sea level rise, and reduced freshwater input to estuaries. Air quality, already poor in the region's major urban areas, could decline even further as hot, humid weather increases, leading to increased incidences of respiratory illness."

Please document these statements.

A20. As with the Alaska example (Q16), this example of regional vulnerability to climate change is based on the discussions from a workshop on the impacts of climate change. The Final Workshop Report has not yet been completed. The workshop on New England was held in Durham, New Hampshire, September 3-5, 1997.

New England's natural resources draw many tourists to the region annually (Goss 1995; DOI and DOC reports). Currently severe storms modify the region's vegetation (Foster et al 1997; Foster and Boose 1992). Warmer and drier conditions would lead to shifts in forest species throughout New England (Davis and Zabinski, 1992). Coastal areas are likely to be affected by intensified storms and sea level rise (Smith and Tirpak 1989). Declines in air quality may lead to increased respiratory illnesses (Smith and Tirpak 1989).

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Health Effects

Q21. On page 13 of your written testimony you also state the following:

"Health Effects: According to the World Health Organization, the vulnerability of human populations to climate change varies across populations depending on environmental circumstances, social resources, and preexisting health status. In general, developing countries are more vulnerable to climate change than developed countries because of their limited capital and their greater dependence on natural resources. Climate change increases the risk of heat-related mortality and the potential for the spread of vector-borne diseases, such as malaria, dengue and yellow fever, and encephalitis, and non-vector borne diseases such as cholera and salmonellosis. The incidence of infectious diseases, which are still the world's leading cause of fatalities, may also increase."

Please document these statements.

A21. Increases in the risk of heat related mortality are documented in *Climate Change and Human Health*, A.J. McMichael, A. Haines, R. Slooff and S. Kovats editors, World Health Organization, Geneva, 1996, pages 55-62, and in *Climate Change 1995 – Impacts, Adaptations and Mitigation of Climate Change: Scientific – Technical Analyses*, Chapter 18 (attached). See also the study requested in Q22.

The potential spread of vector borne diseases and non-vector borne diseases is documented in the WHO report. See in particular Chapter 4, Effects on biological disease agents. That chapter discusses research on the likelihood of changes in the geographic distributions of vector borne diseases such as malaria, dengue and yellow fevers, and encephalitis; changes in transmission potential due to changes in the life-cycle dynamics of vectors and infectious parasites; and changes in the incidence of water and food borne infectious diseases such as cholera and salmonellosis. Research on these topics is also summarized in the IPCC Report chapter.

18

Human Population Health

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CONTENTS

EXECUTIVE SUMMARY

The sustained health of human populations requires the continued integrity of Earth's natural systems. The disturbance, by climate change, of physical systems (e.g., weather patterns, sea-level, water supplies) and of ecosystems (e.g., agroecosystems, disease-vector habitats) would therefore pose risks to human health. The scale of the anticipated health impacts is that of whole communities or populations (i.e., it is a public health, not a personal health, issue). These health impacts would occur in various ways, via pathways of varying directness and complexity, including disturbance of natural and managed ecosystems. With some exceptions, relatively little research has yet been done that enables quantitative description of these probable health impacts.

It is anticipated that most of the impacts would be adverse. Some would occur via relatively direct pathways (e.g., deaths from heat waves and from extreme weather events); others would occur via indirect pathways (e.g., changes in the range of vector-borne diseases). Some impacts would be deferred in time and would occur on a larger scale than most other environmental health impacts with which we are familiar. If long-term climate change ensues, indirect impacts probably would predominate.

Populations with different levels of natural, technical, and social resources would differ in their vulnerability to climate-induced health impacts. Such vulnerability, due to crowding, food insecurity, local environmental degradation, and perturbed ecosystems, already exists in many communities in developing countries. Hence, because of both the geography of climate change and these variations in population vulnerability, climate change would impinge differently on different populations.

- An increased frequency or severity of heat waves would cause an increase in (predominantly cardiorespiratory) mortality and illness (High Confidence). Studies in selected urban populations in North America, North Africa, and East Asia indicate that the number of heat-related deaths would increase severalfold in response to two general circulation model (GCM)–modeled climate change scenarios for 2050. In very large cities, this would represent several thousand extra deaths annually. Although this heat-related increase in deaths would be partially offset by fewer cold-related deaths, there are insufficient data to quantify this tradeoff; further, this balance would vary by location and according to adaptive responses (Medium Confidence).
- If extreme weather events (droughts, floods, storms, etc.) were to occur more often, increases in rates of death, injury, infectious diseases, and psychological disorders would result (High Confidence).
- Net climate change-related increases in the geographic distribution (altitude and latitude) of the vector organisms of infectious diseases (e.g., malarial mosquitoes, schistosome-spreading snails) and changes in the life-cycle dynamics of both vector and infective parasites would, in aggregate, increase the potential transmission of many vector-borne diseases (High Confidence). Malaria, of which there are currently around 350 million new cases per year (including two million deaths), provides a central example. Simulations with first-generation mathematical models (based on standard climate-change scenarios and incorporating information about the basic dynamics of climatic influences on malaria transmission) predict an increase in malaria incidence in Indonesia by 2070 and—with a highly aggregated model—an increase from around 45% to around 60% in the proportion of the world population living within the *potential* malaria transmission zone by the latter half of the next century. Although this predicted increase in *potential* transmission encroaches mostly into temperate regions, actual climate-related increases in malaria incidence (estimated by one model to be of the order of 50–80 million additional cases annually, relative to an assumed global background total of 500 million by 2100) would occur primarily in tropical, subtropical, and less well protected temperate-zone populations currently at the margins of endemically infected areas. Some localized decreases may also occur (Medium Confidence).
- Increases in non-vector-borne infectious diseases such as cholera, salmonellosis, and other food- and water-related infections also could occur, particularly in tropical and subtropical regions, because of climatic impacts on water distribution, temperature, and microorganism proliferation (Medium confidence).
- The effects of climate change on agricultural, animal, and fisheries productivity, while still uncertain, could increase the prevalence of malnutrition and hunger and their long-term health impairments, especially in children. This would most probably occur regionally, with some regions likely to experience gains, and others losses, in food production (Medium Confidence).
- There would also be many health impacts of the physical, social, and demographic disruptions caused by

rising sea levels and by climate-related shortages in natural resources (especially fresh water) (Medium Confidence).

- Because fossil-fuel combustion produces both carbon dioxide and various primary air pollutants, the climate change process would be associated with increased levels of urban air pollution. Not only is air pollution itself an important health hazard, but hotter temperatures, in urban environments, would enhance both the formation of secondary pollutants (e.g., ozone) and the health impact of certain air pollutants. There would be increases in the frequency of allergic disorders and of cardiorespiratory disorders and deaths caused by various air pollutants (e.g., ozone and particulates) (High Confidence).
- A potentially important category of health impact would result from the deterioration in social and economic circumstances that might arise from adverse impacts of climate change on patterns of employment, wealth distribution, and population mobility and settlement. Conflicts might arise over dwindling environmental resources (Medium Confidence).
- Stratospheric ozone is being depleted concurrently with greenhouse gas accumulation in the troposphere. Although there are some shared and interactive atmospheric processes between disturbances of the stratosphere and troposphere, both they and their health impacts arise via quite distinct pathways. A sustained 10–15% depletion of stratospheric ozone over several decades would cause increased exposure to ultraviolet radiation and an estimated 15–20% increase in the incidence of skin cancer in fair-skinned populations (High Confidence). Lesions of the eye (e.g., cataracts) also may increase in frequency, as might vulnerability to some infectious diseases via adverse effects on immune function (Medium Confidence).

Adaptive options to minimize health impacts include improved and extended medical care services; environmental management; disaster preparedness; protective technology (housing, air conditioning, water purification, vaccination, etc.); public education directed at personal behaviors; and appropriate professional and research training. It also will be important to assess in advance any risks to health from proposed technological adaptations (e.g., exposures that could result from using certain alternative energy sources and replacement chemicals for chlorofluorocarbons; effects of pesticide use on resistance of vector organisms and their predator populations).

There is immediate need for improved and internationalized monitoring of health-risk indicators in relation to climate change. Existing global monitoring activities should encompass health-related environmental and bioindicator-species measurements and, where appropriate, direct measures of human population health status. To assist the evolution of public understanding and social policy, the health sciences must develop improved methods, including integrated predictive models, to better assess how climate change (and other global environmental changes) would influence human health.

In conclusion, the impacts of global climate change, particularly if sustained in the longer term, could include a multitude of serious—but thus far underrecognized—impacts on human health. Human population health is an outcome that integrates many other inputs, and it depends substantially on the stability and productivity of many of Earth's natural systems. Therefore, human health is likely to be predominantly adversely affected by climate change and its effects upon those systems.

18.1. Introduction

18.1.1. *Climate Change and Human Population Health: The Nature of the Relationship*

Global climate change over the coming decades would have various effects upon the health of human populations (WHO, 1990; Haines and Fuchs, 1991; McMichael, 1993; Last, 1993; *Lancet*, 1994). Because of the nature of the exposures involved, the scale of these climate-related changes would, in general, apply to whole populations or communities, rather than to small groups or individuals. The assessment of health impacts therefore focuses on changes in rates of death or disease in populations.

Many of the health impacts of climate change would occur via processes that are relatively unfamiliar to public-health science. They would not occur via the familiar toxicological mechanisms of localized exposure to environmental contaminants, nor via locally determined influences on the spread of infectious diseases. Instead, many of the impacts would arise via the indirect and often delayed effects of disturbances to natural systems and their associated ecological relationships. For example, changes in background climate may alter the abundance, distribution, and behavior of mosquitoes and the life cycle of the malarial parasite, such that patterns of malaria would change. Climate change also would have varied regional effects on agricultural productivity, so that some vulnerable populations may experience nutritional deprivation. There also would be some rather more readily predictable health impacts, arising, for example, from more frequent or severe heatwaves.

On a wider canvas, several of the world's ecosystems that are important in sustaining human health already have been weakened by damage, habitat loss, and species/genetic depletion. These include agricultural lands and ocean fisheries and the terrestrial ecosystems that influence the transmission of infectious diseases. Climate change may, via various processes, exacerbate those ecosystem disturbances. Because an ecosystem comprises a suite of interacting components, in which member organisms relate to the whole suite rather than to individual parts, the uncoupling of relationships by climate change could initiate a cascade of disturbances that might jeopardize human population health.

The range of potential major types of health impact is shown in Figure 18-1. For simplicity, they have been classified as "direct" and "indirect," according to whether they occur predominantly via the direct impact of a climate variable (temperature, weather variability, etc.) upon the human organism or are mediated by climate-induced changes in complex biological and geochemical systems or by climatic influences on other environmental health hazards.

18.1.2. *Forecasting Health Impacts: The Challenge to Health Science*

Predictions of future trends in population health are readily made in relation to actual current exposures—for example, future lung cancer rates can be predicted as a function of a population's current cigarette smoking habits (Peto *et al.*, 1994). It is unusual to make predictions on the basis of some anticipated future profile of exposure (e.g., smoking habits in the year 2020), yet this is the nature of the present exercise: Potential health impacts are being assessed in relation to future scenarios of climate change. There are inevitable, multiple uncertainties in such an approach (McMichael and Martens, 1995).

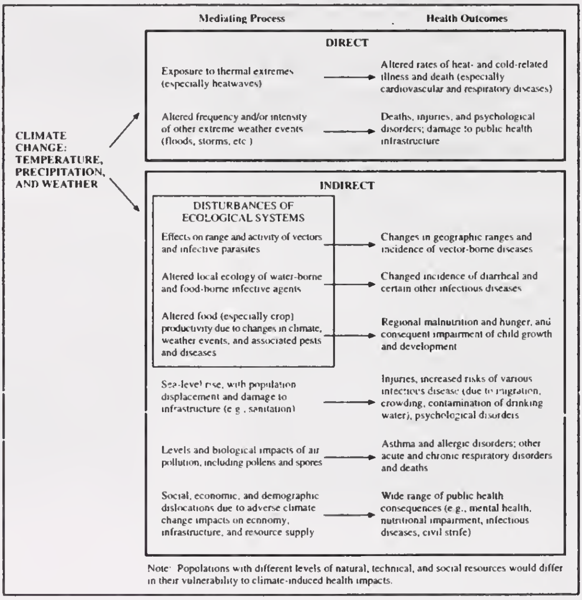

Figure 18-1: Ways in which climate change can affect human health.

Some aspects of climate change and its first-level impacts (on sea level, coastal ecosystems, forests, agriculture, fisheries, etc.), as projected by IPCC Working Group I, would lie outside the range of recorded human health experience. Hence, the forecasting of human health impacts must rely principally upon reference to historical analogy (where available) and reasonable extrapolation, judgment, and the use of integrated mathematical models (Niessen and Rotmans, 1993; McMichael and Martens, 1995). Most of the health impact modeling to date has been at a highly aggregated global or regional level, with no capacity to make finer-grained predictions. Ongoing developments in modeling techniques include the incorporation of complex nonlinear relationships and feedback processes, dealing with uncertainty, and richer use of local detail (Alcamo *et al.*, 1994a, 1994b).

Some health impacts can be forecast by relatively simple extrapolation from empirical epidemiological dose-response data. For example, models to predict the mortality impacts of an increase in heatwaves can be based on existing empirical data. However, predicting the health impact of climate-induced shifts in ecological relationships and habitat boundaries (e.g., malarial mosquitoes, agricultural crops) poses a more complex challenge. Equally complex is the task of predicting the various indirect health impacts of such things as sea-level rise or of civil disruption and enforced migration because of deteriorating environments and dwindling resources.

A further difficulty arises with regional predictions. Not only is the ability to predict regional differences in climate change still limited, but human populations differ greatly in their environmental circumstances, social resources, and preexisting health status. They therefore differ in their vulnerability to climate-induced stresses. Although there is generally insufficient information available to make differentiated assessments of health impacts in different populations, the balance of the assessments published to date is that, because of the geography of the impacts of climate change (particularly in relation to infectious disease transmission and food production) and of population vulnerability, many of the anticipated adverse health impacts would be greater in the world's less-developed regions. Nevertheless, in developed countries, demographic trends including population aging and increasing levels of disability, chronic illness, and coastal retirement may increase the vulnerability of populations.

Although it is tempting to compile a list of discrete health impacts, it is important that the systemic quality of the impact of climate change be understood. There would be many cross-links, including interactions of climate change with other, coexisting environmental changes. Further, the attempts of society to mitigate the health effects of climate change may actually exacerbate some of them. For example, increased use of fertilizers to compensate for a decline in local agricultural production can increase algal blooms and hence the risk of cholera or shellfish poisoning; or the relocation of populations from drought-stricken areas might introduce them to unfamiliar pathogens (or introduce their unfamiliar pathogens). Neither the scope of this chapter nor available scientific knowledge allows comprehensive consideration of these issues.

18.1.3. Sensitivities and Thresholds

Forecasting health impacts requires knowledge of, first, the sensitivity of change in population health status in response to climate change and, second, of any associated thresholds. "Sensitivity" refers to the rate of change in health outcome per unit change in climate (however defined), whereas "threshold" refers to a sudden change in slope or curvature in that dose-response graph (e.g., a certain amount of climate change may be tolerated before an impact on some particular health outcome occurs).

Although there is only limited information on the sensitivities and thresholds of human health response to climate change, some illustrative comments can be made:

- The impact of thermal stress depends on physiological tolerance thresholds being exceeded (see Section 18.2.1). For example, most studies of heat-related mortality show that increased mortality occurs only after a critical temperature has been exceeded for a certain duration. This critical temperature varies geographically, reflecting socioeconomic differences, physiological acclimatization, and cultural-technical adaptation.
- Infectious disease pathogens and insect pests are normally constrained by bioclimatic thresholds. That is, there is a range of climatic conditions with upper and lower thresholds within which a population of organisms is viable (Dobson and Carper, 1993). These thresholds account for seasonal and longer-term fluctuations in the distribution and abundance of most organisms. The uncoupling, by climate change, of previously stable ecological relationships between species would reveal other thresholds as population imbalances pass critical points.
- Changes in the distribution of organisms (e.g., mosquitoes) that spread vector-borne diseases (e.g., malaria) would occur if climate change causes their geographic range to shift. This shift would reflect the critical thresholds of temperature, precipitation, and humidity (i.e., the bioclimatograph) for vector maturation and persistence. For example, the range of *Plasmodium vivax* malaria is limited because the parasite cannot develop inside its mosquito host at temperatures below 14–16°C (Gilles, 1993). Further, blood-feeding arthropods feed and reproduce only above certain temperatures and need less time to complete their life cycle as temperatures increase above that threshold (Curto de Casas and Carcavallo, 1984; Burgos *et al.*, 1994). Threshold effects also apply to the life cycle of the infecting parasite.
- Some animal and plant populations would be unable to migrate or adapt behaviorally to climate change, in part because of constraints imposed by non-climate

variables such as day-length and soil type. Other species with either migratory or dispersive activity (particularly arthropod and weed pests in agriculture and disease vectors that affect human health) would cope with the shifts in climate zones. Humans generally would be less sensitive to changes in background climate because of their capacity to adapt via culture, technology, migration, and behavior.

- The sensitivity of health-outcome response depends on population susceptibility. For example, the impact of a climate-related increase in exposure to infectious agents would depend on prior contact (i.e., herd immunity), on general biological resilience (especially nutritional and immune status), and on population density and patterns of interpersonal contact. Social infrastructure and health-care resources also would condition the impact. In general, the most vulnerable populations or communities would be those living in poverty, with a high prevalence of undernutrition, chronic exposure to infectious disease agents, and inadequate access to social and physical infrastructure.

Table 18-1 lists illustrative examples of the relative sensitivity of selected human health responses to key aspects of climate change. It also summarizes what is known about thresholds in those responses. Further, the "conditionality" of response (i.e., the extent to which it is modulated by other influences) is indicated. This latter criterion is important: Many factors (including the intrinsic vulnerability of the local population) influence the determination of health status, and many of these would condition the health impact of climate change.

Further, many of the impacts of climate change would depend on parameters other than the central changes in mean values. For example, weather variability would be important for extreme events; rates of change would influence the production in ecosystems (e.g., agriculture and fisheries); and the ecology of infectious disease vectors is sensitive to many aspects of climate, including changes in the day-night differential in temperature. These aspects of climate change would vary in their relative importance for different health impacts, as illustrated in Table 18-2. However, information on such details is still rather incomplete.

18.1.4. Major Trends in World Health: Backdrop to Climate Change Impacts

Information about levels and time trends in specific health outcomes facilitates both the prediction and the appraisal of the health impacts of climate change. For example, patterns of malaria and malnutrition are changing around the world in response to various other changes in social, biological, and ecological circumstances. Any predicted impact of climate change upon such health outcomes should be assessed either by differentiating that impact from those of other independent background trends or, if appropriate, by assessing its interactive impact with those other, coexisting influences.

The main contemporary features of world health (World Bank, 1993; Murray and Lopez, 1994) are as follows: (1) near-worldwide increases in life expectancy [with the ex-Eastern Bloc countries standing in sharp recent contrast (Feachem, 1994)], (2) a decline in infant and child mortality in most developing countries, (3) persistent gradients in health status between rich and poor (within and between populations), (4) reductions in certain vaccine-preventable diseases (e.g., polio and measles), (5) increases in the chronic noninfectious diseases of adult life

***Table 18-1:** Examples of important aspects of the relationship of selected health outcomes to climate change.*

Health Outcome	Sensitivity[a]	Conditionality[b]	Thresholds
Climate Stress/Mortality	+++	++	Temperature 33°C[c]
Climate Stress/Morbidity	+		
Allergy	++	++	Not applicable
Asthma	+	+	Not applicable
Vector-Borne Diseases (malaria, yellow fever, dengue, onchocerciasis, encephalitis)[d]	++(+)	++++	Temperature isotherms and humidity levels (bioclimatic functions) e.g., 10°C: *Ae.* mosquito, 14–16°C: *P. vivax* parasite
Other Infectious Diseases (e.g., cholera)	+(++)		Temperature thresholds for algal and bacterial proliferation in sea- and freshwater—optimal ranges

++++ = great effect, + = small effect, (+) = possible additional effect

[a] Extent of change in health outcome per unit change in climate (equivalent to "slope" of regression line).

[b] Extent to which sensitivity depends on preceding and coexistent circumstances (i.e., notions of vulnerability/susceptibility and interactive effects).

[c] Based principally on northeastern U.S. data. Critical temperature depends on local climate and population acclimatization.

[d] See also Table 18-3.

Table 18-2: Probable relative impact on health outcomes of the aspects of climate change.

Health Outcome	Aspects of Climate Change: Change in Mean Temperature	Extreme Events	Rate of Change of Climate Variable	Day-Night Difference
Heat-Related Deaths and Illness		+++		+
Physical and Psychological Trauma due to Disasters		++++		
Vector-Borne Diseases	+++	++	+	++
Other Infectious Diseases	+	+		
Food Availability and Hunger	++	+	++	
Consequences of Sea-Level Rise	++	++	+	
Respiratory Effects				
– Air Pollutants	+	++		+
– Pollens, Humidity	++			
Demographic Disruption	++	+	+	

Notes: ++++ = great effect, + = small effect; empty cells indicate no known relationship.

(especially heart disease, diabetes, and certain cancers) in urban middle classes in rapidly developing countries, and (6) widespread increases in HIV infection. Rates of disease and death from cigarette smoking are likely to escalate markedly in many countries over the coming decades, as the tobacco industry takes advantage of freer trade and market-based economies (Peto *et al.*, 1994). In many urban populations, drug abuse and violence are increasing.

There appears to be a widespread increase in the tempo of new and resurgent infectious diseases (Levins *et al.*, 1994). This primarily reflects the combination of environmental and demographic changes in the world, plus increases in antibiotic and drug resistance, pesticide resistance, and decreased surveillance (Morse, 1991; CDC, 1994a). The interaction of local climate change with other disruptions of ecosystems may have facilitated various infectious disease outbreaks: the emergence of rodent-borne hantavirus pulmonary syndrome in the United States during 1992–3; various rodent-borne arenaviruses in Africa and South America; the spread of harmful algal blooms—and its association with cholera (which is now affecting more nations worldwide than at any earlier time this century); the rapid resurgence of dengue in the Americas since 1981; and the occurrence of dengue and malaria at higher altitudes than previously recorded (Levins *et al.*, 1994).

Many other important influences on population health are changing over time. For example, new vaccines are being developed, and existing ones are being used more widely; contraception is becoming more widely used, with benefits to maternal and child health; and safe drinking water is becoming available, albeit slowly, to an increasing proportion of householders in poorer countries. Other adverse effects (from cigarettes, drugs, urban traffic, social breakdown, violence, etc.) are increasing widely, and persistent widespread poverty remains a major structural impediment to improved health (WHO, 1995a). Against this complex balance sheet, it is inevitably difficult to estimate the likely net impact on population health status after the additional inclusion of climate change.

18.2. Potential Direct Health Impacts of Climate Change

The direct effects of climate change upon health result from changes in climate characteristics or short-term weather extremes that impinge directly on human biology. The following subsections deal with the health impacts of thermal stress and extreme weather events.

18.2.1. Health Impacts of Altered Patterns of Thermal Stress

Many studies, particularly in temperate countries, have observed a J-shaped relationship (often more generally referred to as a U-shaped relationship) between daily outdoor temperature and daily death rate: Mortality is lowest within an intermediate comfortable temperature range. The graph is not symmetrical; the death rate increases much more steeply with rising temperatures, above this comfort zone, than it does with falling temperatures below that zone (Longstreth, 1989; Kalkstein, 1993; Kunst *et al.*, 1993; Touloumi *et al.*, 1994). Relatedly, death rates in temperate countries appear to be affected across a wider band of decreasing, cold, temperatures than that for increasing, hot, temperatures (Kilbourne, 1992; Kunst *et al.*, 1993). Because death rates in temperate and subtropical zones are higher in winter than in summer (Kilbourne, 1992), it is a reasonable expectation that milder winters in such countries would entail a reduction in cold-related deaths and illnesses. However, since summer-related deaths appear to be more related to temperature extremes than are winter-related deaths, this reduction may not fully offset the heat-related increases. Further, this balance of gains and losses would vary among geographic regions and different populations. The issue of balance is examined further later in this section.

Quantitative interpretation of the impacts of altered daily-temperature distribution also is hampered by the fact that, for both heat-related and cold-related deaths, many of the apparent excess deaths occur in already-vulnerable persons (especially the elderly and the sick). Some analyses indicate that, in the absence of extreme temperatures, many of those persons would have died in the near future. This "mortality displacement" issue also will be considered further.

Global warming is predicted to increase the frequency of very hot days (see Chapter 6, *Climate Models–Projections of Future Climate*, of the IPCC Working Group I volume). The frequency of such days in temperate climates (e.g., USA, UK, Australia) would approximately double for an increase of 2–3°C in the average summer temperature (e.g., CDC, 1989; Climate Change Impacts Review Group UK, 1991). Extensive research has shown that heat waves cause excess deaths (Weihe, 1986; Kilbourne, 1992). Recent analyses of concurrent meteorological and mortality data in cities in the United States, Canada, the Netherlands, China, and the Middle East provide confirmatory evidence that overall death rates rise during heat waves (Kalkstein and Smoyer, 1993; Kunst *et al.*, 1993), particularly when the temperature rises above the local population's threshold value. Therefore, it can be predicted confidently that climate change would, via increased exposure to heat waves, cause additional heat-related deaths and illnesses (Kalkstein, 1993; Haines *et al.*, 1993).

The effect of extreme heat on mortality is exacerbated by low wind, high humidity, and intense solar radiation (Kilbourne, 1992). Indeed, these meteorological elements can be treated synoptically, to evaluate the net impact of weather on human health. For example, recent studies in the United States have described "oppressive" air masses (analogous to the meteorologist's "stagnating" air masses), which represent synoptic meteorological situations that exceed physiological tolerance levels. This approach recognizes that humans principally respond to the umbrella of air that surrounds them rather than to individual meteorological elements (Kalkstein, 1993). It also should be noted that concurrent hot weather and air pollution have interactive impacts on health (Katsouyanni *et al.*, 1993; see also Section 18.3.5).

Healthy persons have efficient heat regulatory mechanisms that cope with increases in temperature up to a particular threshold. The body can increase radiant, convective, and evaporative heat loss by vasodilation (enlargement of blood vessels in the skin) and perspiration (Horowitz and Samueloff, 1987; Diamond, 1991). Further, some acclimatization to persistent oppressive weather conditions can occur within several days (Kilbourne, 1992). Nevertheless, the risk of death increases substantially when thermal stress persists for several consecutive days (Kalkstein and Smoyer, 1993). The elderly and very young are disproportionately affected because of their limited physiological capacity to adapt. Although some individuals die from heat exhaustion or heatstroke, the deaths associated with very hot weather are predominantly associated with preexisting cardiovascular and respiratory disorders, as well as accidents (Larsen, 1990a, 1990b). Although there is less evidence on nonfatal illness episodes, it is a reasonable general assumption that thermal stress also increases rates of morbidity.

Socioeconomic factors may have important modulating effects on thermal stress-related mortality. From studies in the United States, the extent of protection from air conditioning remains unclear (Ellis and Nelson, 1978; Larsen, 1990a; Rogot *et al.*, 1992; Kalkstein, 1993). Of more general importance, people living in poverty, including segments of many urban populations in developing countries, are particularly vulnerable to heat stress. Poor housing, the urban heat island effect, and lack of air conditioning are among the primary causes (Kilbourne, 1989). Complete acclimatization may take up to several years (Babeyev, 1986), rendering immigrants (e.g., rural-to-urban) vulnerable to weather extremes for a considerable time. Ongoing rapid increases in urbanization (see Chapter 12) will increase the number of vulnerable persons.

The question in relation to the abovementioned notion of "mortality displacement" is: Would some of those who die during heat waves have succumbed soon afterward from preexisting frailty or disease (Kalkstein, 1993; U.S. EPA, in press)? Various time-series analyses indicate a "deficit" in daily deaths for up to a month after heat waves (e.g., Figure 18-2), and U.S.-based research suggests that 20–40% of the deaths occurring during heat waves would have occurred within the next few weeks (Kalkstein, 1993). A related uncertainty is whether, as the frequency of heat waves increases, the mortality excess remains constant or whether, as some research suggests, successive heat waves entail a progressive lessening of the associated mortality peak.

Kalkstein (1993) made predictions of heat-related mortality for selected urban populations in North America, North Africa, and East Asia in relation to IPCC-specified climate-change scenarios. This entailed, first, identifying for each population

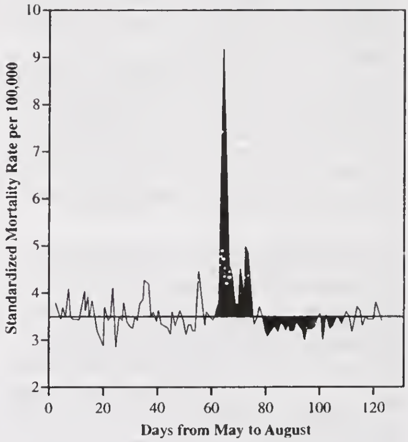

Figure 18-2: Daily summer mortality during a New York heatwave, 1966 (Kalkstein, 1993).

setting the synoptic weather situations that are "oppressive" (i.e., exceed physiological tolerance levels). The annual number of oppressive synoptic situation days was then predicted for the climate-change scenarios, and the annual total of associated excess deaths was estimated. Model-based predictions of the numbers of additional deaths attributable to heat during a typical summer in a future warmer world were thus obtained. Two sets of predicted mortality increases were made: one assuming that the population does not acclimatize and the other assuming partial acclimatization (i.e., complete physiological acclimatization but without improved socioeconomic conditions such as the development of more protective housing).

Consider the population of Atlanta, for example. Presently, Atlanta experiences an average of 78 heat-related deaths each summer. Under the climate projections of the Geophysical Fluid Dynamics Laboratory (GFDL) 1989 (transient) climate-change model, and assuming no change in population size or age profile, this number would increase to 191 in the year 2020 and to 293 in the year 2050. If population acclimatization occurs, the annual total would increase less, to 96 and 147 in those two years. Under the UKTR (transient) model run, the corresponding four projections of heat-related mortality are 20–40% higher than for the GFDL model run: 247 and 436 deaths (unacclimatized, 2020 and 2050) and 124 and 218 deaths (acclimatized, 2020 and 2050). These and other results for selected North American cities, Shanghai, and Cairo indicate that the annual number of heat-related deaths would, very approximately, double by 2020 and would increase several-fold by 2050. Thus, in very large cities with populations displaying this type of sensitivity to heat stress, climate change would cause several thousand extra heat-related deaths annually.

As mentioned earlier, the seasonal death rates in developed countries are highest in winter (Kilbourne, 1992; Tan, 1994). In temperate-zone countries, death rates increase particularly during periods of severe winter weather. However, no single study has yet been published that allows a direct comparison of the anticipated winter gains and summer losses that would accompany global warming. A substantial proportion of winter-related deaths are from cardiovascular disease (Kunst *et al.*, 1993; Langford and Bentham, 1995). It is likely that this increased risk of cardiovascular disease reflects an increased cold-induced tendency for blood to clot (Keatinge *et al.*, 1989), perhaps exacerbated by the fibrinogen-enhancing effect of winter respiratory infections (Woodhouse *et al.*, 1994). The relative importance of respiratory infections and cardiovascular diseases to anticipated reductions in mortality, and how these would vary geographically, remains uncertain. One recent British study has forecast that approximately 9,000 fewer winter-related deaths (estimated to represent a reduction of 2–3%) would occur annually by the year 2050 in England and Wales, under typical climate-change scenarios that entail 2–2.5°C wintertime increases (Langford and Bentham, 1995). Just over half the avoided deaths would be from ischaemic heart disease and stroke, with chronic bronchitis and pneumonia each contributing 5–10%. Other researchers have concluded that a significant portion of the overall winter-related mortality is due to respiratory infections such as influenza (Curwen, 1991). Since these respiratory infections depend upon aerosol transmission—usually in confined, poorly ventilated places—a small rise in winter temperatures should reduce this risk if it encouraged outdoor activities and improved ventilation. However, annual influenza outbreaks do not appear to correlate with mean winter or monthly temperature (CDC, 1994b; Langford and Bentham, 1995).

Overall, the sensitivity of death rates to hotter summers is likely to be greater than to the accompanying increase in average winter temperature. The overall balance is difficult to quantify, and also would depend on the population's capacity for adaptive responses. However, research to date suggests that global warming would, via an increased frequency of heat waves, cause a net increase in mortality and associated morbidity. This conclusion must be qualified by noting that there is an imbalance in the published research—most of which refers to developed, non-tropical, countries.

18.2.2. Health Impacts of Weather Variability and Extreme Events

Global warming may affect ocean currents, air currents, and atmospheric humidity (see Chapter 6, *Climate Models–Projections of Future Climate*, of the IPCC Working Group I volume). Any consequent changes in weather variability may alter the frequency and severity of extreme weather events: bushfires, droughts, floods, storms, and landslides (Gordon *et al.*, 1992; Meehl *et al.*, 1992). However, some of these relationships remain uncertain (e.g., for tropical cyclones; see Lighthill *et al.*, 1994) and have proven difficult to model with GCMs. Such events increase deaths, injuries, infectious diseases, stress-related disorders, and the many adverse health effects associated with social disruption, environmentally enforced migration (Myers, 1993), and settlement in urban slums. Health impacts would be greatest on those communities that are most exposed and have the fewest technical and social resources.

Low-lying, poorly resourced populations would be particularly vulnerable to an increase in frequency of storms and storm surges. In the 1970 Bangladesh cyclone, mortality varied from around 5% inland to almost 50% in coastal communities. Widespread destruction of food supplies may also occur; in 1970, two-thirds of fishing activities along the coasts and plains in Bangladesh were destroyed, along with 125,000 animals (Alexander, 1993). In Andhra Pradhesh, India, in 1970, many victims died when wind and rain caused the collapse of houses (Sommer and Mosely, 1972).

Flash floods and landslides (see Chapter 12) would increase in frequency in regions experiencing increased torrential rainfall. Heavy rains can erode soil, thereby impairing agricultural productivity. Flooding also can affect the incidence of vector-borne diseases. On the one hand, flood waters may wash away mosquito eggs/larvae; on the other hand, residual water may increase mosquito populations and consequent infectious diseases. In southeastern Australia, epidemics of Ross River virus infection follow heavy rains in the Murray-Darling basin (Nicholls, 1993). Flooding also may affect the transmission of diarrheal diseases: In Bolivia, for example, flooding associated with El Niño in 1983 led to a 70% increase in salmonella infections, particularly in children (Telleria, 1986).

Flash flooding is a leading cause of weather-related mortality in the United States (French and Holt, 1989). Damage to homes and displacement of residents may facilitate the spread of infectious diseases because of crowded living conditions. Flooding can contaminate water sources with fecal material or toxic chemicals. Flooding also increases runoff from agricultural lands and urban stormwater systems (Thurman *et al.*, 1991, 1992). Water resources thus are contaminated by toxic chemical wastes, agricultural chemicals, and pathogens (e.g., *Cryptosporidium*). Hazardous exposure may arise from contaminated drinking water and from edible fish that bioaccumulate contaminants.

The many psychosocial effects of natural disasters have been studied in survivors of storms, floods, earthquakes, and fires (e.g., Gregg, 1989). Severe disturbance (including "post-traumatic stress disorder") usually affects only a minority, many of whom recover (de Girolamo and McFarlane, 1994)—although children in affected families may show developmental problems over the ensuing years (Titchener and Frederic, 1976). The level of psychological impact may depend upon the suddenness and unexpectedness of the impact, the intensity of the experience, the degree of personal and community disruption, and long-term exposure to the visual signs of the disaster (Green, 1982; Green *et al.*, 1991). Data from disasters in developing countries are sparse, but a follow-up study after the disastrous 1988 floods in Bangladesh showed increased behavioral disorders in young children (Durkin *et al.*, 1993).

Two final comments on extreme events are appropriate here. First, a major effect of extreme climatic events on human health has been malnutrition and starvation due to severe drought and its consequences (Escudero, 1985). This, in turn, causes increased susceptibility to infection (Tomkins, 1986). Second, there is evidence that environmental degradation, unequal access to resources, and population growth may be potent factors in provoking conflict (Homer-Dixon *et al.*, 1993). By affecting water and food supply, climate change could increase the possibility of violent conflicts in a number of regions.

18.3. Potential Indirect Health Impacts of Climate Change

The indirect effects of climate change upon health are those that do not entail a direct causal connection between a climatic factor (such as heat, humidity, or extreme weather event) and human biology.

18.3.1. Vector-Borne Diseases

The transmission of many infectious diseases is affected by climatic factors. Infective agents and their vector organisms are sensitive to factors such as temperature, surface water, humidity, wind, soil moisture, and changes in forest distribution (Bradley, 1993). This applies particularly to vector-borne diseases (VBDs) like malaria, which require an intermediate organism such as the mosquito to transmit the infective agent. It is therefore projected that climate change and altered weather patterns would affect the range (both latitude and altitude), intensity, and seasonality of many vector-borne and other infectious diseases. In general, increased warmth and moisture would enhance transmission of these diseases. However, any such climate-related redistribution of disease may also entail—perhaps in conjunction with other environmental stresses—some localized reductions in rates of infection.

The sustained (or endemic) transmission of VBDs requires favorable climatic-environmental conditions for the vector, the parasite, and, if applicable, the intermediate host species. For vectors with long life spans (e.g., tsetse flies, bugs, ticks), vector abundance is a major determinant of disease distribution; arthropods that transmit VBDs generally thrive in warmth and moisture. For vectors with short life spans (e.g., mosquitoes, sandflies, blackflies), the temperature-sensitive extrinsic maturation period of the parasite is of critical importance. The geographic distributions of many of the parasites, both unicellular (protozoa) and multicellular (e.g., flukes and worms), correlate closely with temperature (Gillet, 1974; Shope, 1991). The geographic distributions of vector-borne viral infections, such as dengue and yellow fever, are affected by temperature and surface water distribution. For many VBDs, such as plague and hantavirus, rodents act as intermediate infected hosts or as hosts for the arthropod vector (Wenzel, 1994); rodent activity would also tend to increase in a warmer world (Shope, 1991).

In tropical countries, VBDs are a major cause of illness and death. For the major VBDs, estimates of numbers of people at risk and infected, and of VBD sensitivity to climate change, are shown in Table 18-3. While the potential transmission of many such diseases would increase (geographically or from seasonal to year-round) in response to climate change, the capacity to control these diseases also will change. New or improved vaccines can be expected; some vector species can be constrained by use of pesticides. Nevertheless, there are uncertainties and risks here, too: for example, long-term pesticide use breeds resistant strains and kills many predators of pests.

18.3.1.1. Malaria

Malaria remains a huge global public-health problem, currently causing around 350 million new infections annually, predominantly in tropical countries. Malaria is caused by an infective parasite (plasmodium) transmitted between humans by a mosquito vector. Its incidence is affected by temperature, surface water, and humidity (Gill, 1920a, 1920b; Sutherst, 1983). Although anopheline mosquito species that transmit malaria do not usually survive where the mean winter temperature drops below 16–18°C, some higher-latitude species are able to hibernate in sheltered sites. Sporogonic development (i.e., the extrinsic incubation phase of

Table 18-3: Major tropical vector-borne diseases and the likelihood of change of their distribution with climate change.

Disease	Vector	Population at Risk (million)[a]	Number of People Currently Infected or New Cases per Year	Present Distribution	Likelihood of Altered Distribution with Climate Change
Malaria	Mosquito	2,400[b]	300–500 million	Tropics/Subtropics	+++
Schistosomiasis	Water Snail	600	200 million	Tropics/Subtropics	++
Lymphatic Filariasis	Mosquito	1,094[c]	117 million	Tropics/Subtropics	+
African Trypanosomiasis (Sleeping Sickness)	Tsetse Fly	55[d]	250,000–300,000 cases per year	Tropical Africa	+
Dracunculiasis (Guinea Worm)	Crustacean (Copepod)	100[e]	100,000 per year	South Asia/ Arabian Peninsula/ Central-West Africa	?
Leishmaniasis	Phlebotomine Sand Fly	350	12 million infected, 500,000 new cases per year[f]	Asia/Southern Europe/Africa/ Americas	+
Onchocerciasis (River Blindness)	Black Fly	123	17.5 million	Africa/Latin America	++
American Trypanosomiasis (Chagas' disease)	Triatomine Bug	100[g]	18 million	Central and South America	+
Dengue	Mosquito	1,800	10–30 million per year	All Tropical Countries	++
Yellow Fever	Mosquito	450	<5,000 cases per year	Tropical South America and Africa	++

+ = likely, ++ = very likely, +++ = highly likely, ? = unknown.
[a]Top three entries are population-prorated projections, based on 1989 estimates.
[b]WHO, 1995b.
[c]Michael and Bundy, 1995.
[d]WHO, 1994a.
[e]Ranque, personal communication.
[f]Annual incidence of visceral leishmaniasis; annual incidence of cutaneous leishmaniasis is 1-1.5 million cases/yr (PAHO, 1994).
[g]WHO, 1995c.

the plasmodium within the mosquito) ceases below around 18°C for *Plasmodium falciparum* and below 14°C for *P. vivax*. Above those temperatures, a small increase in average temperature accelerates the parasite's extrinsic incubation (Miller and Warrell, 1990). Temperatures of 20–30°C and humidity above 60% are optimal for the anopheline mosquito to survive long enough to incubate and transmit the parasite.

Until recent decades, parts of today's developed world were malarious. These included the United States, southern Europe, and northern Australia. In the last century, outbreaks of *P. vivax* malaria occurred in Scandinavia and North America. Although climate change would increase the potential transmission of malaria in some temperate areas, the existing public-health resources in those countries—disease surveillance, surface-water management, and treatment of cases—would make reemergent malaria unlikely. Indeed, malaria is most likely to extend its spread (both latitude and altitude) and undergo changes in seasonality in tropical countries, particularly in populations currently at the fringe of established endemic areas (Martens *et al.*, 1994). Newly affected populations would initially experience high case fatality rates because of their lack of natural acquired immunity.

Box 18-1. Examples of Modeling the Future Impact of Climate Change upon Malaria

Mathematical models have been recently developed for the quantitative prediction of climate-related changes in the potential transmission of malaria (e.g., Sutherst, 1993; Matsuoka and Kai, 1994; Martin and Lefebvre, 1995). Note the use of the important word "potential" here; the models are primarily predicting where malaria could occur as a function of climate and associated environment, irrespective of the influence of local demographic, socioeconomic, and technical circumstances.

A simple model has been used for Indonesia, based on empirical historical data from selected provinces on the relationship of annual average temperature and total rainfall to the incidence of malaria (and dengue and diarrhea) (Asian Development Bank, 1994). The model forecasts that annual malaria incidence (currently 2,705 per 10,000 persons) would, in response to the median climate-change scenario, increase marginally by 2010 and by approximately 25% by 2070. Because of the limited technical information, it is not easy to appraise these particular forecasts.

A more complex integrated global model has been developed by Martens *et al.* (1994). This model takes account of how climate change would affect the mosquito population directly—i.e., mosquito development, feeding frequency, and longevity—and the incubation period of the parasite inside the mosquito (see Figure 18-3). As a highly aggregated model, it does not take account of local environmental-ecological factors, and it therefore cannot be regarded as a source of precise projections. The model's output refers to geographic changes in *potential* transmission (i.e., the range within which both the mosquito and parasite could survive with sufficient abundance for sustained transmission of malaria). This is not, therefore, a projection of actual disease incidence, and it must be interpreted in relation to local control measures, health services, parasite reservoir, and mosquito densities. Further, until such models have been validated against historical data sets, their predictions must be viewed cautiously.

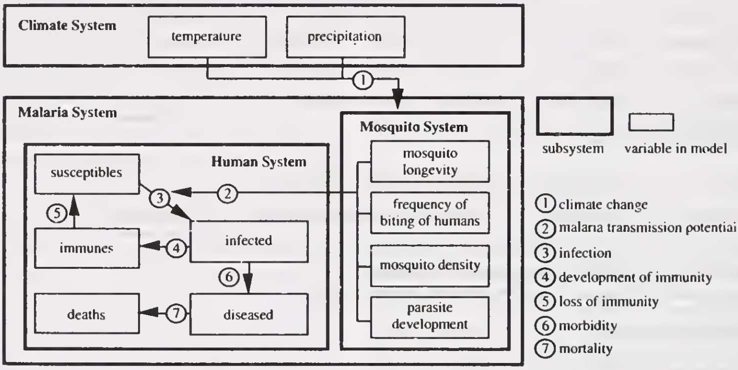

Figure 18-3: Systems diagram of a model designed to assess the impact of climate change on the potential transmission of malaria (adapted from Martens *et al.*, 1994).

This particular model predicts widespread increases in the potential habitat range and the "vectorial capacity" of the mosquito, and therefore potential malaria transmission, in response to climate change. For example, using GCM predictions of 3–5°C increases in global mean temperature by the year 2100, the malaria epidemic potential of the mosquito population is estimated to increase twofold in tropical regions and substantially more than tenfold in temperate climates (Martens *et al.*, 1995a). Overall, there is an increase from around 45% to around 60% of the world population living within the potential malaria transmission zone by the latter half of the next century. However, most of the developed countries have effective control and surveillance measures that should preclude reintroduction of endemic malaria. In the already endemic areas, especially in the subtropics, malaria may increase (although in some hot climates, further temperature increases may shorten the life span of mosquitoes, and local malaria transmission would then decrease). In particular, in adjoining areas of lower endemicity or unstable malaria, the occurrence of infection is far more sensitive

Box 18-1 (continued)

to climate variation, so climate change may have a marked effect on its incidence and stability. Simulations with this model, using several different GCMs, predict a climate-induced increase in the incidence of annual malaria cases of approximately 50–80 million in response to a temperature rise of around 3°C by the year 2100, relative to an assumed approximate base of 500 million annual cases in a 2100 world without climate change (Martens *et al.*, 1995b).

Another recent attempt at aggregated global modeling (Martin and Lefebvre, 1995) has predicted that potential malaria transmission would spread to higher latitudes, while some currently stable endemic areas near the equator would become unstable, leading to reductions in population immunity levels.

Such models, despite their highly aggregated predictions and simplifying assumptions, provide indicative information about the likely impact of climate change on the potential transmission of vector-borne diseases (assuming that other relevant factors remain constant). There is a clear need for validation of these models and for incorporating more extensive detail into them. Meanwhile, this line of research has begun to elucidate the interdependent relationships among climate change, vector population dynamics, and human disease dynamics.

Recent evidence of the responsiveness of malaria incidence to local climate change comes from observations of marked increases in malaria incidence in Rwanda in 1987, when atypically hot and wet weather occurred (Loevinsohn, 1994), and annual fluctuations in falciparum malaria intensity in northeast Pakistan that correlated with annual temperature variations during the 1980s (Bouma *et al.*, 1994). Hence, it is a reasonable prediction that, in eastern Africa, a relatively small increase in winter temperature could extend the mosquito habitat and thus enable falciparum malaria to reach beyond the usual altitude limit of around 2,500 m to the large, malaria-free, urban highland populations, e.g., Nairobi in Kenya and Harare in Zimbabwe. Indeed, the monitoring of such populations around the world, currently just beyond the boundaries of stable endemic malaria, could provide early evidence of climate-related shifts in malaria distribution (Haines *et al.*, 1993).

18.3.1.2. African Trypanosomiasis

African trypanosomiasis, or "sleeping sickness," is transmitted by tsetse flies. The disease is a serious health problem in tropical Africa, being generally fatal if untreated. Research in Kenya and Tanzania shows only a very small difference in mean temperature between areas where the vector, *Glossina morsitans*, does and does not occur. This indicates that a small change in temperature may significantly affect the limits of the vector's distribution (Rogers and Packer, 1993).

18.3.1.3. American Trypanosomiasis (Chagas' Disease)

American trypanosomiasis is transmitted by insects of the subfamily *Triatominae*. It is a major problem in Latin America, with 100 million people at risk and 18 million infected (WHO, 1995c). An estimated 15–20% of infected people develop clinical Chagas' disease. Most of the triatomine vector species need a minimum temperature of 20°C for feeding and reproduction (Curto de Casas and Carcavallo, 1984), but at higher temperatures (28–30°C) they feed more frequently, have a shortened life cycle, and an increased population density (Carcavallo and Martinez, 1972, 1985). At even higher temperatures, the most important vector species, *Triatoma infestans*, doubles its reproductive rate (Hack, 1955).

18.3.1.4. Schistosomiasis

Schistosomiasis is a water-based disease caused by five species of schistosomal flukes. Water snails act as the intermediate host (and, strictly speaking, are not active "vectors"). The infection has increased in worldwide prevalence since mid-century, perhaps largely because of the expansion of irrigation systems in hot climates, where viable snail host populations interact with infected humans (White *et al.*, 1972; Grosse, 1993; Hunter *et al.*, 1993).

Data from both the field and the laboratory indicate that temperature influences snail reproduction and growth, schistosome mortality, infectivity and development in the snail, and human-water contact (Martens *et al.*, 1995b). In Egypt, for example, water snails tend to lose their schistosome infections during winter, but if temperatures increase, snails may mediate schistosomiasis transmission throughout the year (Gillet, 1974; WHO, 1990). Predictive modeling indicates that a change in background temperatures may cause the infection to extend to currently unaffected regions. Fluctuations in temperature may also play an important role in optimizing conditions for the several life-cycle stages of schistosomiasis (Hairston, 1973).

18.3.1.5. Onchocerciasis (River Blindness)

Onchocerciasis, or "river blindness," is a VBD affecting approximately 17.5 million people—some in Latin America, most in West Africa. The vector is a small blackfly of the genus *Simulium*, and the infectious agent is the larva of the *Onchocerca volvulus* parasite. This threadlike worm damages the skin, the lymphatic system, and, in the most extreme cases, the eye. Climate affects the occurrence of onchocerciasis because the vector requires fast-flowing water for successful reproduction (WHO, 1985), and the adult vector can be spread by wind.

A recent simulation study on the potential impact of climate change on blackfly populations in West Africa showed that if temperature and precipitation were to change across parts of the sub-Sahel, as predicted by the Goddard Institute for Space Studies (GISS) GCM (Hansen *et al.*, 1988), blackfly populations may increase by as much as 25% at current breeding sites (Mills, 1995). Since these vectors can travel hundreds of kilometers on wind currents, new habitats in previously unsuitable areas could be quickly colonized by blackflies, introducing onchocerciasis into new areas (Garms *et al.*, 1979; Walsh *et al.*, 1981; WHO, 1985).

18.3.1.6. Trematode Infections

Some trematode infections, such as fascioliasis (a liver fluke that currently affects around 2.4 million persons), would be affected by climate changes because the life cycle and population size of the snail host are very sensitive to temperature. Similarly, the incidence of cercarial dermatitis (skin inflammation) would be increased at higher temperatures. This infection is currently found in Europe (Beer and German, 1994) and the United States (CDC, 1992), where it causes "swimmer's itch"; its incidence has recently increased in Russia (Beer and German, 1993) and in very poor rural communities in developing countries.

18.3.1.7. Vector-Borne Viral Infections

Many vector-borne infective agents are viruses. The human-infecting arboviruses (i.e., arthropod-borne viruses) generally have a mosquito vector. Arboviral infections span a wide clinical spectrum, from those that cause mild feverish illness or subclinical infections to those causing severe and often fatal encephalitis (brain inflammation) or hemorrhagic fever. Under favorable environmental conditions, an arboviral disease can become epidemic (population-wide), from a local endemic base or by its introduction to a previously unaffected area. The distribution and abundance of vectors are influenced by various physical factors (temperature, rainfall, humidity, and wind) and biological factors (vegetation, host species, predators, parasites, and human interventions) (WHO, 1990). Temperature also affects the rapidity of the virus' life cycle—e.g., the extrinsic incubation period for the mosquito-hosted stage of the yellow fever virus varies from several weeks to 8–10 days, depending on temperature.

Increased temperature and rainfall in Australia would influence the range and intensity of various vector-borne viral infections. For example, certain arthropod vectors and natural vertebrate hosts would spread southward and proliferate in response to warming and increased rain, resulting in increased incidence of arboviral infections such as Murray Valley encephalitis (which can cause serious brain damage), Ross River virus (which causes multiple, often long-lasting joint inflammation), and dengue (e.g., Sutherst, 1993; Nicholls, 1993).

Dengue is a severe influenza-like disease, which in some cases may take the form of a hemorrhagic fever, which can cause an average of 15% mortality without proper medical attention. Dengue is transmitted by the *Aedes aegypti* mosquito, as is urban yellow fever. In parts of Asia, dengue also is transmitted by *Ae. albopictus*, which now is colonizing North and South America. Research in Mexico has shown that an increase of 3–4°C in average temperature doubles the rate of transmission of the dengue virus (Koopman *et al.*, 1991). Although there is no clear evidence of regional climatic influence, annual epidemics of dengue have returned to Central America over the past decade (as they did about twenty years ago in Asia), and, in Mexico, dengue has recently spread to previously unaffected higher altitudes (Herrera-Basto *et al.*, 1992). *Ae. aegypti* mosquitoes, once limited to 1,000 meters altitude by temperature in Colombia, have been recently reported above 2,200 meters. The habitat of the mosquito is restricted to areas with a mean midwinter temperature of more than 10°C. Epidemic transmission of dengue is seldom sustained at temperatures below 20°C (Halstead, 1990).

18.3.1.8. Other Vector-Borne Diseases

VBDs are now relatively rare in most developed countries; however, it has been predicted that various VBDs might enter or increase in incidence in the United States because of higher temperatures (Longstreth, 1989; Freier, 1993; Martens *et al.*, 1994); Venezuelan equine encephalitis, dengue, and leishmaniasis could extend into the southern United States; Western equine encephalitis might move further north within the United States (Reeves *et al.*, 1994). The dengue-transmitting *Ae. albopictus* mosquito, which is more cold-hardy than *Ae. aegypti*, is now well established in the United States and may extend toward Canada if temperatures increase.

Climate change would influence the global pattern of VBDs via other disturbances of ecological relationships. For example, it would bring together vertebrate animals of different species and would thereby expose animals to new arthropod vectors. Warming (and rising sea levels) would displace some human populations, perhaps resulting in migration into wilderness areas where zoonotic infectious agents are being transmitted in silent wildlife cycles. Migratory humans would thus be at risk of infection with enzootic (i.e., locally prevalent animal-infecting) agents. Climate-induced changes in ecology also could force the rapid evolution of infectious agents, with newly emergent strains of altered virulence or pathogenicity. Additionally, changes in climate means and variability can disrupt predator/prey ratios, thus loosening natural controls on pests and pathogens.

Two other general points should be noted. First, because vector control methods exist for many of these diseases, developed countries should be able to minimize their impact. Second, however, the quicker "turnover" of the life cycle of parasites at higher temperatures will increase their likelihood of evolving greater resistance to drugs and other control methods. This would pose a particular problem to those tropical countries with high infection rates and limited socioeconomic resources.

18.3.2. Water-Borne and Food-Borne Infectious Diseases

Climatic effects on the distribution and quality of surface water—including increases in flooding and water shortages that concentrate organisms, impede personal hygiene, and impair local sewerage—would influence the risks of diarrheal (including cholera) and dysentery epidemics, particularly in developing countries. Diarrheal diseases can be caused by a large variety of bacteria (e.g., *Salmonella*, *Shigella*, and *Campylobacter*), viruses (e.g., *Rotavirus*), and protozoa (e.g., *Giardia lamblia*, amoebas, and *Cryptosporidium*). Many of these organisms can survive in water for months, especially at warmer temperatures, and increased rainfall therefore could enhance their transport between groups of people. An increased frequency of diarrheal disease is most likely to occur within impoverished communities with poor sanitation. There have been outbreaks of diarrheal disease after flooding in many such settings. If flooding increased, there also would be risks of outbreaks of infection in developed countries within temporary settlements of displaced communities.

The cholera organism, *Vibrio cholerae*, can survive in the environment by sheltering beneath the mucous outer coat of various algae and zooplankton—which are themselves responsive to climatic conditions and to nutrients from wastewater and fertilizers (Epstein, 1992; Smayda, 1990; Anderson, 1992). Increases in coastal algal blooms may therefore amplify *V. cholerae* proliferation and transmission. This might also assist the emergence of new genetic strains of vibrios. Algal blooms also are associated with biotoxin contamination of fish and shellfish (Epstein *et al.*, 1993). With ocean warming, toxins produced by phytoplankton, which are temperature-sensitive, could cause contamination of seafood more often (see also Chapter 16), resulting in increased frequencies of amnesic, diarrheic and paralytic shellfish poisoning and ciguatera poisoning from reef fish. Thus, climate-induced changes in the production of both aquatic pathogens and biotoxins may jeopardize seafood safety for humans, sea mammals, seabirds, and finfish.

Climate change also could create a problem via the warming of aboveground piped-water supplies. In parts of Australia, for example, there has been a seasonal problem of meningoencephalitis caused by the *Naegleria fowleri* amoeba, which proliferates in overland water pipes in summer (NHMRC, 1991). Soil-based pathogens (e.g., the tetanus bacterium and various fungi) would tend to proliferate more rapidly with higher temperature and humidity, depending on the effectiveness of microclimatic homeostatic mechanisms. Higher temperatures would also increase the problem of food poisoning by enhancing the survival and proliferation of bacteria, flies, cockroaches, and so forth in foodstuffs.

18.3.3. Agricultural Productivity and Food Supplies: Effects upon Nutrition and Health

Food, as energy and nutrients, is fundamentally important to health. Malnutrition is a major cause of infant mortality, physical and intellectual stunting in childhood, and immune impairment (thus increasing susceptibility to infections). Currently, around one-tenth of the world's population may be hungry (Parry and Rosenzweig, 1993) and a larger proportion malnourished—although estimates differ according to definition.

Human societies have evolved farming methods to counter various local climatic and environmental constraints on agriculture, especially via irrigation, fertilization, mechanization, and the breeding of better-adapted varieties. Today, as gains in per capita agricultural productivity appear to be diminishing, widespread land degradation accrues, and access to new arable land is declining, the further possibility exists of adverse effects of climate change upon aspects of world food production (Houghton *et al.*, 1990; Kendall and Pimentel, 1994). The impacts of climate change upon crop and livestock yield would be realized within a complex setting that encompasses climate change scenarios, crop yield response, pest population response, demographic trends, patterns of land use and management, and social and economic responses.

18.3.3.1. Modes of Climatic Impact upon Agricultural Productivity

Global warming would alter regional temperature and rainfall. Changes in these two major influences on agriculture, and consequent reductions in soil moisture, could impair the growth of many crops. Increases in the intensity of rainfall in some regions would exacerbate soil erosion. The net global impact of these climate-related changes upon food production is highly uncertain (Reilly, 1994). Although the IPCC assessment is uncertain about the overall impact, it foresees productivity gains and losses in different regions of the world (see Chapter 13). While productivity may increase initially, longer-term adaptations to sustained climate change would be less likely because of the limitations of plant physiology (Woodward, 1987).

Climate change also could affect agriculture by long-term changes in agroecosystems, by an increased frequency and severity of extreme events, and by altered patterns of plant diseases and pest infestations (e.g., Farrow, 1991; Sutherst, 1991). Debate persists over whether enrichment of the atmosphere with carbon dioxide will have a "fertilization effect" (Idso, 1990b; Bazzar and Fajer, 1992; Körner, 1993). Experiments consistently indicate that C_3 plants (e.g., wheat, soya beans, rice, and potatoes) would respond more positively than C_4 plants (e.g., millet, sorghum, and maize), which would be unaffected (see Chapter 13). This effect may be temperature-dependent (Vloedbeld and

Leemans, 1993). Such influences on the climatically optimal mix of crop species would disturb patterns of traditional agriculture in some regions.

18.3.3.2. Impacts upon Food Supplies, Costs, and the Risk of Hunger

Since climate change may threaten food security in poorer countries within the semi-arid and humid tropics (Rosenzweig *et al.*, 1993; see also Chapter 13), poorer countries, already struggling with large and growing populations and marginal climatic conditions, would be particularly vulnerable to food shortages, malnutrition, and demographic disruption. In such countries, there is minimal capacity for adaptive change (Leemans, 1992). Already in Africa, more than 100 million people are "food insecure," many of them in the arid Sahel region. The cost of food on world markets would increase if crop production declined in the world's mid-latitude breadbasket regions. The large minority of the world population that already suffers from malnutrition would then face an increased threat to health from agricultural failure and rising food costs. A recent analysis predicts an extra 40–300 million people at risk of hunger in the year 2060 because of the impact of climate change, on top of a predicted 640 million people at risk of hunger by that date in the absence of climate change (Rosenzweig *et al.*, 1993).

18.3.3.3. Impacts of Climate Change on Non-Cereal Food Production

Climate change may influence the production of noncrop food supplies, including animal productivity. For example, the U.S. Environmental Protection Agency has identified several infectious diseases—such as the horn fly in beef and dairy cattle and insect-borne anaplasmosis infection in sheep and cattle—that could increase in prevalence in response to climate changes (Rosenzweig and Daniel, 1989). An increase in temperature and temperature extremes also could affect the growth and health of farm animals (Furquay, 1989); young animals are much less tolerant of temperature variation than are adult animals (Bianca, 1976).

Changes in ocean temperatures and currents could affect the base of the marine food web and alter the distribution, migration, and productivity of fish species, a major source of protein for many human populations (Glantz, 1992). Increased soil erosion from intensified rainfall raises the turbidity of lakes and rivers, reducing photosynthesis and therefore fish nutrition. As in agriculture, climate change may contribute to the decline of some fisheries and the expansion of others (see Chapter 16).

18.3.4. Health Impacts of Sea-Level Rise

Each of the vast changes in sea level that have occurred during the past million years, before and after ice ages, typically took many thousands of years. The predicted rise of around half a meter over the next century (see Chapter 7, *Changes in Sea Level*, of the IPCC Working Group I volume) would be much faster than anything experienced by human populations since settled agrarian living began. Such a rise would inundate much of the world's lowlands, damage coastal cropland, and displace millions of persons from coastal and small island communities (see Chapter 12).

Much of coastal Bangladesh and Egypt's heavily populated Nile Delta would be flooded. Some low-lying, small island states such as the Maldives and Vanuatu would be at risk of partial immersion, and many other low-lying coastal regions (for example, eastern England, parts of Indonesia, the Florida Everglades, parts of the northeast coast of Latin America) would be vulnerable. The displacement of inundated communities—particularly those with limited economic, technical, and social resources—would greatly increase the risks of various infectious, psychological, and other adverse health consequences.

Sea-level rise could have a number of other effects, of varying directness, upon public health. In some locations, it could disrupt stormwater drainage and sewage disposal. Poverty and the absence of social infrastructure would compound the health consequences of storm damage, disruption of sanitation, and displacement of coastal dwellers. In many places, industrial and agricultural depletion of groundwater already are causing land subsidence, thus decreasing the threshold for impact. Meanwhile, widespread damage to coral reefs is reducing their capacity to buffer shorelines. Rising seas also would cause saltwater to encroach upon freshwater supplies from estuarine and tidal areas. Some changes in the distribution of infectious disease vectors could occur (e.g., *Anopheles sundaicus*, a saltwater vector of malaria).

18.3.5. Climate and Air Pollution: Impacts on Respiratory and Other Health Disorders

The incidence of respiratory disorders—many of which are caused primarily by dusts, noxious gases, allergic reactions, or infections—may be modulated by climate change. Some of these modulatory effects may occur via extreme temperatures or amplification of pollutant levels. Rapid changes in air masses associated with frontal passages may alter the intensity of respiratory illnesses (Ayres, 1990). People with chronic obstructive pulmonary disease (bronchitis and emphysema) often experience exacerbation during winter.

Seasonal allergic disorders would be affected by changes in the production of pollen and other biotic allergens; plant aeroallergens are very sensitive to climate (Emberlin, 1994). Changes in pollen production would principally reflect changes in the natural and agriculturally managed distribution of many plant species—for example, birch trees, grasses, various crops (e.g., oilseed rape, sunflowers), and ragweed species. Hay fever (allergic rhinitis) increases seasonally and may reflect the impact of pollen release. The seasonal distribution and the causation/exacerbation of asthma is more complex. It peaks in the pollen season and increases again later in the year in temperate climates; in the tropics, asthma occurs more frequently in the wet season (LAIA, 1993; *Lancet*, 1985). In many asthmatic individuals, aspects of weather can exacerbate bronchial hyperresponsiveness. For example, the passage of a cold front followed by strong high pressure was found to be associated with unusually high number of asthma admission days in two U.S. cities (Goldstein, 1980). Sandstorms in Kansas (USA) and the Sudan have been accompanied by increases in bronchitis and asthma (Ayres, 1990).

It is well established that exposure to air pollutants, individually and in combinations, has serious public health consequences. For example, exposure to ozone has been shown to exacerbate asthma and impair lung function in children and the elderly (Beckett, 1991; Schwartz, 1994), and both chronic and acute exposures to fine particles are a cause of excess deaths (Dockery *et al.*, 1993; Pope *et al.*, 1995; Schwartz, 1994) even at exposures below prevailing air-quality standards. Since the combustion of fossil fuels is a major source of both carbon dioxide (a major greenhouse gas) and various air pollutants, climate change can be expected to entail more frequent occasions that combine very hot weather with increases in air-pollutant concentrations. In urban environments, the weather conditions that characterize oppressive air masses (see Section 18.2.1) also enhance the concentrations of air pollutants (Seinfeld, 1986); conditions of low wind speed and high humidity occur periodically in which neither heat nor air pollutants are rapidly dispersed. Further, increases in temperature or in ultraviolet irradiation of the lower atmosphere enhance the chemical reactions that produce secondary photochemical oxidant pollutants such as tropospheric ozone (Akimoto *et al.*, 1993; de Leeuw and Leyssius, 1991; Chamiedes *et al.*, 1994).

In many urban settings, studies have shown that daily mortality from cardiovascular and respiratory diseases is a combined function of temperature and air pollutant concentrations. This combination of exposures is also likely to have interactive impacts on health. Indeed, some epidemiological evidence indicates a synergy (a positive interaction) between stressful weather and various air pollutants, especially particulates, upon mortality (e.g., Shumway *et al.*, 1988; Katsouyanni *et al.*, 1993; Shumway and Azari, 1992). The net effect on morbidity/mortality therefore would be greater than anticipated from prior estimates of the separate effects of weather and pollutants.

18.4. Stratospheric Ozone Depletion and Ultraviolet Radiation: Impacts on Health

Stratospheric ozone depletion is a quite distinct process from accumulation of greenhouse gases in the lower atmosphere (troposphere). Depletion of stratospheric ozone has recently occurred in both hemispheres, from polar regions to mid-latitudes (Kerr and McElroy, 1993; see also IPCC Working Group I volume). The major cause of this ongoing depletion is human-made gases, especially the halocarbons (UNEP, 1994).

The problem can be considered alongside climate change for three reasons: (1) several of the greenhouse gases (especially the chlorofluorocarbons) also damage stratospheric ozone; (2) altered temperature in the troposphere may influence stratospheric temperature and chemistry (Rind and Lacis, 1993); and (3) absorption of solar radiation by stratospheric ozone influences the heat budget in the lower atmosphere (see also IPCC Working Group I volume).

Stratospheric ozone absorbs part of the sun's incoming ultraviolet radiation (UVR), including much of the UV-B and all of the highest-energy UV-C. Sustained exposure to UV-B radiation is harmful to humans and many other organisms (UNEP, 1994). It can damage the genetic (DNA) material of living cells and can induce skin cancers in experimental animals. UV-B is implicated in the causation of human skin cancer and lesions of the conjunctiva, cornea, and lens; it may also impair the body's immune system (Jeevan and Kripke, 1993; Armstrong, 1994; UNEP, 1994).

18.4.1. Skin Cancers

Solar radiation has been consistently implicated in the causation of nonmelanocytic and melanocytic skin cancers in fair-skinned humans (IARC, 1992; WHO, 1994b).

Nonmelanocytic skin cancers (NMSCs) comprise basal cell carcinoma (BCC) and squamous cell carcinoma (SCC). The incidence rates, especially of squamous cell carcinoma, correlate with cumulative lifetime exposure to solar radiation (IARC, 1992; Kricker *et al.*, 1995). Studies of the action spectrum (i.e., the relative biological effect of different wavelengths) for skin carcinogenesis in mice indicate that the UV-B band is primarily responsible for NMSC (Tyrrell, 1994). Malignant melanoma arises from the pigment-producing cells (melanocytes) of the skin. Although solar radiation is substantially involved in melanoma causation (IARC, 1992; Armstrong and Kricker, 1993), the relationship is less straightforward than for NMSC; exposure in early life appears to be a major source of increased risk. The marked increases in incidence of melanoma in Western populations over the past two decades (Coleman *et al.*, 1993) probably reflect increases in personal exposure to solar radiation due to changes in patterns of recreation, clothing, and occupation (Armstrong and Kricker, 1994).

The UN Environment Programme predicts that an average 10% loss of ozone (such as occurred at middle-to-high latitudes over the past decade), if sustained globally over several decades, would cause approximately 250,000 additional cases of NMSC worldwide each year (UNEP, 1994). This prediction assumes that a 1% depletion of stratospheric ozone results in a 2.0% (±0.5%) increase in NMSC incidence (80% of which are BCC). Another estimation of this "amplification factor" gives a figure of 2.25% (Slaper *et al.*, 1992; den Elzen, 1994). At higher geographic resolution, Madronich and de Gruijl (1993) predict that persistence of the ozone losses of the 1979–92 period for several decades would cause the incidence of BCC to increase by 1–2% at low latitude (5°), 3–5% at 15–25°, 8–12% at 35–45°, and, at 55–65°, by 13–15% in the northern hemisphere and 20–30% in the south. They estimate that the percentage increases for SCC would be approximately double those for BCC.

18.4.2. Cataracts and Other Damage to the Eye

The external epithelial (keratotic) layer of the eye, comprising cornea and conjunctiva, absorbs virtually all UVR of less than 290 nm wavelength. Corneal photokeratitis, pterygium (a growth of the conjunctival epithelium), and climatic droplet keratopathy are thought to be UVR-related (Taylor *et al.*, 1989; Gray *et al.*, 1992; WHO, 1994b). Inside the eye, the lens absorbs much of the residual UVR, and this absorbed radiation may cause cataracts (Taylor *et al.*, 1988; Dahlback *et al.*, 1989; West *et al.*, 1989; WHO, 1994b).

Cataracts (lens opacities) are independent of skin pigmentation (unlike skin cancer). They occur predominantly in old age and cause more than half of the world's estimated 25–35 million cases of blindness (Harding, 1991). In Western countries, 5–10% of people aged over 65 have cataracts (Klein *et al.*, 1992). The prevalence often is much higher among elderly, malnourished persons in poor countries, where micronutrient deficiencies and the metabolic consequences of severe diarrheal episodes may contribute to cataract formation (Harding, 1992). Scientific debate persists over the extent of the influence of UV-B upon cataract formation (Dolin, 1994; WHO, 1994b); some epidemiological studies have found clear-cut positive results, but others have not. The relationship is most evident for cortical and posterior subcapsular cataracts but less so for the more commonly occurring nuclear cataracts.

Ocular photodamage by UVR is enhanced by certain clinical drugs used in photochemical therapy that can cause photosensitizing reactions (Lerman, 1988). Various other photosensitizing medications would render individuals generally more susceptible to adverse health effects from increased exposure to UVR; these medications include psoralens, thiazides, phenothiazines, barbiturates, allopurinol, and retinoic acid compounds (Lerman, 1986).

18.4.3. Alteration of Immune Function

Human and animal evidence indicates that UV-B irradiation of skin at quite modest levels causes local and, probably, systemic suppression of immunity (Morison, 1989; Noonan and DeFabo, 1990; Jeevan and Kripke, 1993). Most of the evidence is for local immunosuppression, in which the skin's contact hypersensitivity response is impaired (Giannini, 1986; Yoshikawa *et al.*, 1990; UNEP, 1994). UV-B exposure disturbs the function of the skin's Langerhan cells and stimulates the release of certain cytokines (messenger chemicals) that promote the activity of suppressor T lymphocytes, thus dampening the local immune system (UNEP, 1994).

Evidence for more generalized (i.e., systemic) suppression of immunity comes from studies in humans, which show that sunlight exposure increases the suppressor T cells in blood (Hersey *et al.*, 1983). Although there is evidence in humans of UV-induced changes in the profile of circulating immunologically active lymphocytes for several days to weeks, the extent of systemic immune suppression involved remains uncertain (de Gruijl and van der Leun, 1993). Systemic suppression also occurs in UV-irradiated mice (Kripke, 1981; Jeevan and Kripke, 1990).

Immune suppression would alter susceptibility to infectious diseases (Armstrong, 1994). Exposure to UV-B modifies various immunological reactions in mice that influence the pathogenesis of infectious diseases, such as those due to *Herpes simplex* viruses (Otani and Mori, 1987; Yasumoto *et al.*, 1987), leishmania (Gianinni, 1986; Giannini and DeFabo, 1989), candida (Denkins *et al.*, 1989), and mycobacteria (Jeevan and Kripke, 1989). The relevance of these findings for naturally occurring infectious diseases, and for vaccination efficacy, in humans remains unknown. UNEP (1994) concluded that: "It will be very difficult to assess the role of UV-B radiation on natural infections in human populations. Based on current knowledge, we would predict that an effect of UV-B radiation would manifest as an increase in the severity or duration of disease and not necessarily as an increase in disease incidence."

18.4.4. Indirect Effects of Ozone Depletion upon Human Health

An increase in UV-B irradiance is predicted to impair photosynthesis on land and sea (UNEP, 1994). Although the magnitude is uncertain, and may well not be large, there would be at least a marginal reduction in crop yields (Worrest and Grant, 1989) and in the photosynthetic production of biomass by marine phytoplankton, the basis of the aquatic food chain (Smith and Baker, 1989; Smith *et al.*, 1992). Thus, adverse effects of UV-B upon photosynthesis would, to some extent, reduce global food production.

18.5. Options for Adaptation

Various adaptation strategies are possible to reduce the impacts of climate change on human health. Such adaptation could be developed at the population or individual level. The feasibility of adaptation would be constrained for many of the world's populations by a lack of local resources.

At the population level, environmental management of ecosystems (e.g., freshwater resources, wetlands, and agricultural areas sensitive to invasion by vectors), public health surveillance and control programs (especially for infectious diseases), and introduction of protective technologies (e.g., insulated buildings, air conditioning, strengthened sea defences, disaster warning systems) would be important. Improved primary health care for vulnerable populations could play a significant role in reducing a range of health impacts, including some vector-borne and other communicable diseases, and the effects of extreme events. One example is extension of vaccination coverage, although no suitable vaccines exist for some of the diseases most sensitive to climate change (e.g., dengue and schistosomiasis) or for many of the newly emerging infections.

At the individual level, people should be encouraged to refrain from or to limit dangerous exposures (e.g., by use of domestic cooling, protective clothing, mosquito nets). Such behavioral responses could complement any physiological adaptation that might occur spontaneously through acclimatization (to heat stress) or acquired immunity (to infectious diseases).

In view of limitations to the forecasting of health impacts at this stage of our knowledge, an important and practical form of adaptation would be to improve large-scale monitoring and surveillance systems, especially for vulnerable populations and areas. Recently initiated efforts to observe and monitor aspects of the Earth's environment and ecosystems in relation to climate change now should incorporate health-related monitoring (Haines *et al.*, 1993). Advances in climate forecasting and in the regional integration of ecological and health monitoring (including local vulnerability factors) will facilitate development of early-warning systems.

Finally, if health impacts of climate change are probable and serious, then the only effective long-term basis for mitigation lies in primary prevention at the societal level. This would require acceptance of the Precautionary Principle as the foundation of policy response. This, in turn, would suggest some fundamental, and therefore difficult, reorientations of social, economic, and political priorities. Meanwhile, care must be taken that alternative technologies do not introduce new health hazards.

18.6. Research Needs

- Development and validation of integrated mathematical models for the prediction of health impacts. Such models must draw on multiple scientific disciplines and should take maximal account of regional and local influences on the effects being modeled and on their interaction with other environmental stresses.
- Identification and analysis of current or recent settings in which the health impacts of local or regional climate changes (occurring for whatever reason) can be studied. The apparent recent changeable patterns of infectious diseases around the world may afford good opportunities for clarifying and quantifying the influences of climatic factors.
- Incorporation of health-related measurements in global, regional, and local monitoring activities. This would enhance the early detection of shifts in health risks, the evaluation of alternative indices for monitoring health (including the use of sensitive species as bioindicators), and the opportunity to detect and/or examine previously unsuspected or undocumented environment–health relationships.
- Some specific research needs include:
  - Comparison of impacts of heat waves in urban and rural populations, to clarify the relative importance of thermal stress and air pollutants
  - Examination of the interplay between climatic impacts on forests and other terrestrial ecosystems on the range and dynamics of vector-borne disease
  - Study of factors influencing population vulnerability to climate change.

18.7. Concluding Remarks

Forecasting the health impacts of global climate change entails unavoidable uncertainty and complexity. Human populations vary greatly in their vulnerability to climate changes and in their resources for protection and mitigation. Likewise, the responses of infectious disease vectors to changes in climate depend greatly on other concomitant environmental stresses and the adequacy of control measures and health care systems. Meanwhile, population health status continues to be influenced by a rich mix of cultural and socioeconomic factors. Hence, assessing the health impact of climate change requires a systems-based modeling approach that integrates information about climatic factors, other environmental stresses, ecological processes, and social-economic-political inputs and responses.

Alongside the need for improved health impact assessment capability is a precautionary need to develop global, regional, and local monitoring systems for the early detection of climate-induced changes in human health. There have, indeed, been various recent events that, plausibly, might be early signals of such change. The increased heat-related deaths in India in 1995; the changes in geographic range of some vector-borne diseases; the coastal spread of cholera: Could these be early indications of shifts in population health risk in response to aspects of climate change? Of course, it is not possible to attribute particular, isolated events to a change in climate or weather pattern; other plausible explanations exist for each of them, and a number of different factors may combine to produce each event. However, it is important that we begin to assess patterns of change in the various indices of human health that will provide early insight and will assist further the development of predictive modeling.

There is thus a clear need for enhanced research and monitoring activities. This need reflects the assessment that the potential health impacts of climate change, particularly if sustained in the longer term and if generally adverse, could be a serious consequence of the ongoing anthropogenic changes in the composition of Earth's atmosphere.

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Climate Change 1995

Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses

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Q22. On page 13 of your written testimony you also state the following:

> **"A study of deaths associated with summer time heat stress and winter time illnesses in 44 U.S. cities estimated that climate change could double the number of weather-related deaths. The elderly are at greatest risk in the U.S., and urban populations in developing countries are also especially vulnerable to heat stress."**

Please provide a copy of this study.

A22. The study of weather related deaths referred to in the testimony is L.S. Kalkstein and J.S. Greene, "An evaluation of climate/mortality relationships in large U.S. cities and the possible impacts of a climate change," Environmental Health Perspectives, volume 105, no. 1, January 1997. A copy of the article is attached.

An Evaluation of Climate/Mortality Relationships in Large U.S. Cities and the Possible Impacts of a Climate Change

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A new air mass-based synoptic procedure is used to evaluate climate/mortality relationships as they presently exist and to estimate how a predicted global warming might alter these values. Forty-four large U.S. cities with metropolitan areas exceeding 1 million in population are analyzed. Sharp increases in mortality are noted in summer for most cities in the East and Midwest when two particular air masses are present. A very warm air mass of maritime origin is most important in the eastern United States, which when present can increase daily mortality by as many as 30 deaths in large cities. A hot, dry air mass is important in many cities, and, although rare in the East, can increase daily mortality by up to 50 deaths. Cities in the South and Southwest show lesser weather/mortality relationships in summer. During winter, air mass-induced increases in mortality are considerably less than in summer. Although daily winter mortality is usually higher than summer, the causes of death that are responsible for most winter mortality do not vary much with temperature. Using models that estimate climate change for the years 2020 and 2050, it is estimated that summer mortality will increase dramatically and winter mortality will decrease slightly, even if people acclimatize to the increased warmth. Thus, a sizable net increase in weather-related mortality is estimated if the climate warms as the models predict. ***Key words:*** **acclimatization, air mass, climate and human mortality, climate change, human health, synoptic climatology.** ***Environ Health Perspect*** **105:84–93 (1997)**

The impact of climate on human health continues to draw increased attention as it becomes apparent that human sensitivity to weather is considerable and varies through time and space. The health implications of a possible human-induced climate change has only served to heighten awareness, and two recently published volumes developed by international experts have compiled research to date on retrospective climate/health associations and potential future outcomes (*1,2*).

One of the most intensely studied aspects of climate/health relationships concerns the impact of heat and cold on human mortality. Such studies have taken on increased sophistication, especially in the use of climate modeling, to develop empirical relationships among heat stress, extreme cold, and variations in mortality. In addition, many studies are beginning to consider a number of confounding factors that may alter climate/mortality relationships and may have major implications if the climate warms. For example, what is the role of air conditioning in affecting heat-related human mortality? Do people acclimatize to the heat in warmer locales? Can acclimatization occur within a single summer season? Would many people who die during heat waves have died shortly afterward, regardless of the weather (mortality displacement)? Will decreases in cold-related mortality compensate for increases in heat-related mortality if the earth warms, as many climatologists predict? These are just a sample of the questions that have led to disagreement among scientists who study the impact of climate on mortality.

The goal of this study is to introduce a new, more sophisticated climatological procedure to evaluate the impact of climate on human mortality in 44 cities in the United States. These cities represent all the standard metropolitan statistical areas (SMSAs) in the country with populations of 1 million or greater. In addition, we will discuss the possible implications of a climate warming on mortality totals within these cities, using the most recent climate change scenarios provided by the Intergovernmental Panel on Climate Change (IPCC) for use in its recent impacts assessment (*1*). Although some of the confounding issues described above will be addressed, it is not the aim of this paper to produce estimates that take all of these factors into account. Thus, estimates of climate-related mortality provided here should serve as a springboard for scientists to determine the quantitative impact of various factors described above. However, we are confident that the use of a new climatological procedure which evaluates weather in a more realistic fashion, and the incorporation of updated climate change scenarios designed specifically for impacts analysis, will lead to more accurate estimates of summer and winter weather-related mortality.

Previous Research

Most mortality studies to date have focused on the impact of extremely high and low temperatures on death. Although the most direct impact of heat on the human body is the onset of heat exhaustion or heat stroke, the increase in mortality associated with hot weather cuts across many causes of death. For example, deaths from cardiovascular and respiratory disorders and from some types of accidents typically increase during stressful weather conditions (*3,4*). Heat stroke and heat exhaustion represent only a small proportion of the mortality increase. During hot weather, the total death rate from all causes, and especially from cardiovascular diseases, may be more than double the long-term mean death rate. Because of this diversity in cause of death, in many studies the number of heat-related deaths is determined empirically as the number of deaths occurring in excess of the background expected number (*2*). Thus, total deaths above a baseline, rather than disaggregated causes of death, are often evaluated in weather/mortality studies (*5,6*).

The most recent analyses of heat-related deaths in cities in the United States, Canada, the Netherlands, China, Greece, Germany, and the Middle East provide supporting evidence that overall death rates rise during heatwaves (*6–10*). Virtually all of these studies have documented a threshold temperature beyond which mortality rises rapidly. However, some studies, especially in Western Europe, suggest that mortality rises linearly with increasing temperature, and even moderate heat can lead to excess deaths (*2,6*). We have consistently noted a threshold effect in U.S. cities, and our research does not support the linear increases found in several European studies. Some evaluations have noted the importance of several consecutive days above the threshold temperature, and it appears that the impact of heat becomes most important 1–3 days after the onset of the heat wave.

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Previous studies suggest that a human-induced climate change would increase summer mortality, even if the population adapted somewhat to such a change (*2,11*). The increased frequency and intensity of heatwaves would probably lead to dramatic increases in summer deaths, and because urban structures would not be greatly modified to account for climate alterations, populations would be unable to adapt completely to increasing temperatures. In addition, the recent IPCC Working Group II report suggests that decreases in winter mortality related to a global warming would probably not compensate for predicted summer increases, although there is some uncertainty about this (*1*).

In temperate regions, there is a clear-cut seasonal variation in mortality, and the death rate in winter is 10–25% higher than during the rest of the year (*12*). However, the extent of winter-associated mortality that is directly attributed to low temperatures (and not to seasonal patterns of respiratory infections) has been difficult to determine. Many studies have suggested that, in many locations, daily deaths increase as daily winter temperatures decrease (*13*). However, the existence of a temperature threshold is less evident in winter than in summer (*6,10,14*). In some cold weather locales, such as Montreal and Minneapolis, the increase in mortality with decreasing winter temperature is slight (*15,16*). In less extreme climates, such as The Netherlands and Brisbane, Australia, mortality rates rise linearly with decreasing wintertime temperature (*6,16,17*).

In winter in temperate countries, along with a heightened rate of cardiovascular disease, there are increased deaths from influenza, pneumonia, and accidents (*18,19*). Since these respiratory infections depend upon aerosol transmission, usually in confined, poorly ventilated places, a small rise in winter temperatures may reduce this risk if it encourages outdoor activities and improved ventilation. Conversely, annual influenza outbreaks do not appear to correlate with mean winter monthly temperatures (*18,20*), and the relationship between winter temperatures and deaths from respiratory infection remains uncertain. Thus, the impact of a global warming on winter mortality is more difficult to ascertain than impacts on summer mortality.

The recent use of a synoptic climatological methodology to evaluated weather/mortality relationships has supported and expanded the findings from the temperature-oriented research described above (*21,22*). The synoptic procedure assumes that the population responds to the entire umbrella of air (or air mass) that surrounds them rather than to individual weather elements such as temperature. Thus, the synoptic procedure permits an evaluation of synergistic relations among weather elements; the combined impact of several elements is more significant than the sum of their individual impacts. The synoptic approach involves the development of an automated index that describes the air mass over an area every day (e.g., continental polar air mass, maritime tropical air mass). Days considered homogeneous meteorologically are grouped into air mass categories, and their impact on mortality can then be assessed more logically. The initial use of the synoptic approach (the Temporal Synoptic Index, or TSI) revealed that, for many U.S. cities, a single high risk summer air mass is associated with unusually high mortality (*9,22*). In addition, the synoptic analysis confirmed earlier work which indicated that a climate change, as expressed by general circulation model (GCM) scenarios, would greatly increase summer mortality, even if partial acclimatization occurred (*22*).

The synoptic procedures, such as TSI, used in earlier work are place-specific only; air masses are developed for a locale without regard to other places. Thus, it has been troublesome to compare results from one region to the next using the TSI procedure developed by Kalkstein (*21*), as it is very difficult to identify the same air masses in different locales using this place-specific procedure. In the study described here, a more sophisticated synoptic approach which identifies the same air mass types for a continental-sized area, has been employed. Thus, this new procedure will permit an interregional comparison of high risk air masses, something that has never been attempted before. It is possible that a certain air mass type is high risk in the eastern United States, while it is rather benign in the West. One of the recent breakthroughs in synoptic climatology has been the development of an automated means to identify the same air masses across a large region (*23*); this methodology will be applied here for the first time.

Procedure

The spatial synoptic classification. Unlike most existing air mass-based techniques such as TSI, the spatial synoptic classification (SSC) requires initial identification of the major air masses that traverse the nation, as well as their typical meteorological characteristics. Thus, the SSC, used here to identify air masses associated with unusually high mortality, was developed specifically to classify all days at numerous locales into one of seven predetermined, readily identifiable air mass categories (*23*). These air mass categories are dry polar (DP), dry temperate (DM), dry tropical (DT), moist polar (MP), moist temperate (MM), moist tropical (MT), and transition (T; transitions represent days in which the air mass changes from one type to another). Dry polar air is synonymous with continental polar; it is the coldest, and sometimes the driest, air mass in a region. Cloud cover is often minimal. Dry temperate air is typically an adiabatically warmed Pacific air mass that has descended the lee side of the Rocky Mountains. The air mass is associated with mild, dry conditions in the eastern and midwestern sections of the nation and intrudes most frequently when there is a strong west–east flow aloft. Dry tropical defines the hot and very dry air mass that most often originates from the Desert Southwest or northern Mexico. It is most commonly associated with the hottest and driest conditions and is rather frequent in the Midwest. Moist polar air is cool and humid, with overcast conditions and, frequently, easterly winds. In the eastern United States this air mass is synonymous with maritime polar conditions around the northern flank of a low pressure system. Moist temperate is also associated with overcast, humid conditions, but temperatures and dew points are much higher owing to the close proximity of the responsible front. Moist tropical air masses, commonly recognized as maritime tropical, represent warm, humid conditions found frequently in the warm sector of an open wave cyclone or the western flank of a subtropical anticyclone. Atmospheric instability and convective activity are common within this uncomfortable air mass.

Although there are character similarities within the air masses at different locations, it is noteworthy that significant differences also exist. For example, summer moist tropical air masses are warm and humid at all locales, but mean afternoon temperatures vary from over 33°C in central Texas to about 29°C in New England. Mean dew points range from about 23°C in Florida to 17°C in North Dakota. The frequency occurrence of the air masses are highly variable; for example, moist tropical air occurs on over 70% of summer days in Florida to less than 10% in the high plains of the Dakotas and Nebraska (*24*).

The foundation for the development of the SSC is the proper selection of seed days, which represent the typical meteorological character of each air mass at a location. Each group of seed days for every air mass is chosen by the specification of ranges in afternoon surface temperature, dew point, dew point depression, wind speed, wind direction, cloud cover, diurnal temperature change, and dew point changes every 6 hr. Initial estimates of these criteria are specified for each air mass at each location after careful evaluation of surface meteorological data and maps, and days that satisfy the criteria are selected to represent seed days for the air mass. These seed days are used to classify all other days, and a number of seed days for each air mass is used to develop a robust sample of the typical character of each air mass at each location (*23,24*).

Following seed day selection, discriminant function analysis is used to generate a linear function for each air mass from its group of seed days. Because the goal is to classify each day into one of the pre-existing air masses described above and to use the seed day means as input into the classification, discriminant function analysis was selected as the appropriate classification tool (*25,26*). The day is classified into the category possessing the highest discriminant function score. This results in a calendar listing the air mass to which each day has been assigned.

While a majority of these air mass designations are correct, a significant number of days may be incorrectly classified because of the occurrence of a transition between air masses. Transitions represent changing situations when one air mass is displacing another; a day with a cold front passage represents a good example. To account for this possibility, the SSC performs a second discriminant function analysis to determine whether a transition between air masses occurred during each day [refer to Kalkstein et al. (*23*) for further details].

At many locations in summer, MT air accounts for over 50% of the total daily occurrences (*24*); thus, the MT airmass was subdivided using the procedures described above into three subcategories designated MT1, MT2, and MT3. The dominant characteristic of each of these air masses is moist tropical; however, MT1 is very warm and humid, MT2 is slightly cooler, and MT3 is significantly drier.

Unlike previous synoptic/mortality studies, the SSC provides the unique ability to identify the same air masses across a continental-sized area. Thus, SSC is the ideal synoptic tool to evaluate relationships between air mass type and mortality in this 44-city study.

Mortality data. Mortality data were obtained from the National Center for Health Statistics (NCHS) and contain information on cause, place, and date of death; age; and race of every individual who died in the United States from 1964

Table 1. Summer high risk air masses

		Total		Elderly	
City	Air mass type	Ratio*	Deaths/day	Ratio*	Deaths/day
Anaheim, CA	No high risk air masses	—	—	—	—
Atlanta, GA	DP	1.7	3.6	—	—
	MT1	1.9	2.6	1.8	1.5
Baltimore, MD	MT1	2.7	4.6	—	—
	MT2	1.8	1.4	—	—
	MT3	2.1	2.8	1.9	2.1
Birmingham, AL	MT1	2	1.6	3.4	1.6
Boston, MA	DT	—	—	2.3	5.7*
	MT1	2.3	7.8*	2	6.1*
	MT2	1.8	2.4	—	—
	MT3	1.9	4.0	—	—
Buffalo, NY	MT1	4.8	3.3	2.8	3.2
Chicago, IL	DT	2.7	8.6*	2	5.7*
	MT1	4.1	14.0*	3.1	8.3*
	MT3	2.2	6.8*	2.1	4.8
Cincinnati, OH	MT1	2.7	2.1	2.2	3.4
Cleveland, OH	DT	—	—	7.1	6.7*
	MT3	—	—	2.9	2.1
Columbus, OH	T	—	—	2	0.5
	MT1	2	3.3	—	—
	MT3	1.7	1.0	—	—
Dallas-Ft. Worth, TX	DT	2.6	3.0	2.7	2.0
Denver, CO	No high risk air masses	—	—	—	—
Detroit, MI	DT	2.2	10.1*	2.2	6.2*
	MT1	—	—	5.8	9.4*
	MT2	—	—	1.9	3.5
	MT3	—	—	2.4	4.8
Ft. Lauderdale, FL	No high risk air masses	—	—	—	—
Greensboro, NC	MP	—	—	2	1.5
Hartford, CT	MT1	2.6	2.7	2.5	2.0
	MT3	1.7	1.2	—	—
Houston, TX	DT	8.2	7.6*	—	—
	T	—	—	2.3	1.0
Indianapolis, IN	MT1	3.1	3.1	2.5	2.2
Jacksonville, FL	No high risk air masses	—	—	—	—
Kansas City, MO	DT	2.7	5.1*	2.2	2.3
	MT1	1.9	2.6	1.9	1.7
Los Angeles, CA	MT1	2.1	9.1*	—	—
	DM	2.3	3.2	1.7	2.6
Louisville, KY	MP	—	—	1.8	0.4
	MT1	2.8	2.1	1.9	1.6
Memphis, TN	DP	—	—	2.1	0.3
	DT	13	3.3	7	2.9
	MT1	1.7	1.4	2	1.3
Miami, FL	No high risk air masses	—	—	—	—
Minneapolis, MN	DT	2.1	4.1	2	2.6
	MT1	3.5	6.1*	4	4.6
	MT3	1.8	1.3	2	0.9
Nassau County, NY	DT	5.6	5.9*	—	—
	MT1	2.8	4.9	1.8	3.6
New York, NY	DT	8.4	49.2*	7.1	38.0*
	MT1	6.3	30.2*	6.3	21.9*
	MT3	1.7	8.4*	1.9	6.3*

to 1991 (*27*). A daily mortality calendar was constructed for total and elderly (>65 years old) deaths for the period of record for summer (June, July, and August) and winter (December, January, and February). Although certain causes of death, such as respiratory and cardiovascular disease, are deemed to be more sensitive to variations in meteorology, a number of studies such as this one do not subdivide mortality data into these specific categories. Recent analyses indicate that a wide range of causes of death are impacted by weather, which suggests that disaggregation of mortality causes will not necessarily lead to improved relationships (*2*). However, additional research on the impact of weather situations upon specific causes of death is most desirable and will be an outgrowth of this study. All mortality data were standardized to account for changes in the total population of the SMSA of the individual cities during the period of record. A direct standardization procedure was used, and a mortality trend line was constructed for the period of record based on mean daily mortality for each year of record. Mortality was then expressed as a deviation around the temporal baseline level (*21*).

The mean daily mortality for each synoptic category, along with the standard deviation (SD), was determined to ascertain whether particular categories exhibited distinctively high or low mortality values. Daily mortality was also sorted from highest to lowest during the period of record to determine whether certain synoptic categories were prevalent during the highest and lowest mortality days for each of the cities. To determine which air masses are high risk, the ratio of frequency during the highest 50 mortality days to total frequency of each air mass was determined for the 44 cities. If the ratio was determined to be statistically significantly greater than one (at 95% CI), that air mass was determined to be high risk. It may be argued that, using a procedure such as this, a number of air masses might be considered high risk based simply on statistical significance, resulting in some spurious identification of high risk air masses. However, if it appears that the same air masses are deemed high risk within the different cities, or if there is some regional homogeneity in high risk air masses, it is likely that this represents a true physical relationship between air mass type and mortality, rather than a statistical artifact.

Mortality associated with a particular weather episode may not occur immediately, and there may be a significant lag time between oppressive weather and deaths. Thus, analyses included synoptic category/mortality relationships for 0, 1, 2, and 3 day lags; the lag that resulted in the highest mortality for the high risk category was retained.

One interesting feature about high risk air masses is their large standard deviation in daily mortality. Thus, although these air masses contain virtually all the high mortality days for a given locale, they also include days when mortality may be at or below mean levels (*21*). Thus, a within-category stepwise multiple regression analysis was performed on all days within the high risk synoptic category with daily mortality as the dependent variable. The independent variables included several meteorological elements that vary considerably within synoptic category: maximum temperature, minimum temperature, mean daily cloud cover, maximum dew point temperature, minimum dew point temperature, morning and afternoon windspeed, and morning and afternoon visibility. In addition, two nonmeteorological independent variables were included. The first, day in sequence, notes how a particular high risk category day is positioned within a consecutive day sequence. For example, if the day in question is the third consecutive day of a high risk synoptic category, it is assigned a value of 3 (all single day occurrences of high risk category days are assigned a value of 1). The second nonmeteorological independent variable, time of season, evaluates the intraseasonal timing of the high risk category day, as previous studies have shown that oppressive weather in August might exert less influence on mortality than similar weather in June (*9*). For example, a high risk category day on June 1 (first day of summer) is assigned a value of 1, June 2 is

Table 1 Continued. Summer high risk air messes

		Total		Elderly	
City	Air mass type	Ratio[a]	Deaths/day	Ratio[a]	Deaths/day
New Orleans, LA	MT1	1.9	1.5	1.8	1.5
Newark, NJ	DT	4.4	5.7*	2.8	4.0
	MT1	1.8	4.2	—	—
Philadelphie, PA	DT	21.1	32.0*	9.4	23.2*
	MT1	3.5	10.1*	3.1	6.6*
	MT3	2	3.3	1.8	2.7
Phoenix, AZ	MT1	1.8	0.9	—	—
Pittsburgh, PA	MT1	—	3.9	—	3.4
	DT	—	14.8*	—	2.3
	MT3	—	—	—	2.3
Portland, OR	DT	5.1	5.0*	5.9	3.7
Providence, RI	MT1	6.7	6.8*	7.8	5.4
	MT2	3.5	0.2	—	—
	MT3	1.8	2.6	1.8	2.2
Riverside, CA	DT	3.0	1.7	—	—
Salt Lake City, UT	T	—	—	1.8	0.5
Sen Antonio, TX	MM	—	—	1.9	0.3
	DT	2.5	1.1	—	—
San Diego, CA	No high risk eir masses	—	—	—	—
San Francisco, CA	DT	8.8	9.3*	—	—
	T	2.1	2.0	—	—
San Jose, CA	No high risk air masses	—	—	—	—
Seettle, WA	No high risk air masses	—	—	—	—
St. Louis, MO	DT	5.2	15.0*	5.3	11.3
	MT1	2.2	2.3	2.5	2.0
Tampa, FL	MM	2.3	1.1	—	—
	T	1.8	1.3	2.2	1.1
	MT1	2.1	2.9	—	—
Washington, DC	MT1	—	—	1.8	2.3

Abbreviations: DP, dry polar; MT, moist tropical; DT, dry tropicel; T, transition; MP, moist polar; DM, dry temperate; MM, moist temperate. See text for subcategories of MT.
[a]Percentage of top 50 mortality days within the air mass/percent frequency of air mass occurrence. Expected value equals 1.0; e value of 2.0 indicates that air mass occurs twice as frequently within the top 50 mortality days than would be expected based on seasonal frequency of air mass.
*High risk air messes with meen excess mortality >5.0.

assigned a value of 2, and so on. The algorithms developed from the within-high risk category regressions are used to provide estimates of the number of deaths attributed to heat for each category day.

Once relationships between retrospective synoptic events and mortality have been established, it is possible to apply this information to estimate the impact of climate change on human mortality. This was achieved by using scenarios from general circulation models (GCMs) to estimate the frequency of air masses under various climate change situations. GCMs are dynamic mathematical models that simulate the physical processes of the atmosphere and oceans in an attempt to predict future global and regional climate (*2,28*). They incorporate representations of land surface processes, sea-ice related processes, and many more complex processes of the climate system. GCMs take the form of mathematical equations, which are then solved with computers using a three-dimensional global grid. Typical resolutions are about 250 km in the horizontal and 1 km in the vertical. Many physical processes, such as those related to clouds and precipitation, take place on much smaller spatial scales and therefore are modeled with less precision.

Although the weather elements necessary to run the SSC can be extracted from GCM output, it should be noted that the veracity of GCMs is a matter of much debate and controversy (*2*). Thus, the estimates of mortality using the climate change scenarios should be viewed with caution, although we believe that they provide information regarding possible outcomes if the climate changes as suggested by GCMs.

Three GCM scenarios recommended for use by the IPCC were incorporated into this study: the Geophysical Fluid Dynamics Laboratory (GFDL) model, the United Kingdom Meteorological Office (UKMO) model, and the Max Planck Institute for Meteorology Model (*29*). Each model provided two sets of transient runs: one for the decades centered around 2020 and the other centered around 2050. Using the new sets of weather data provided by the GCMs, estimates of air mass frequencies were developed for each model. High risk air masses were isolated, and estimates of mortality under the scenarios were developed using the algorithms described above.

When measuring the impact of a climate change on future mortality, the question of acclimatization must be considered. Will people within each city respond to heat as they do today? Or will their reactions be similar to those people who presently live in hotter climates? To account for the acclimatization possibility, analog cities were established for each evaluated city. These analogs represent cities whose present climate approximates the estimated climate of a target city as expressed by the GCMs. For example, the use of the GFDL 2050 scenario to estimate the future climate in New York City yields results similar to the present climate of St. Louis. Because St. Louis residents are fully acclimatized to this regime, the weather/mortality algorithm developed for St. Louis is used for New York City to account for full acclimatization.

It is unlikely that the population will fully acclimatize to increasing warmth associated with a global warming because urban structures, especially for the vulnerable poor, will likely not be modified to account for temperature increases (*2*). However, it is difficult to assess to what degree acclimatization will actually occur,

Table 2. Winter high risk air masses

City	Air mass type	Total Deaths/day	Elderly Deaths/day
Anaheim, CA	DP	1.1	—
	DT	—	2.0
Atlanta, GA	DP	1.3	1.5
Baltimore, MD	No high risk air masses	—	—
Birmingham, AL	DT	0.6	0.4
	DP	1.4	—
Boston, MA	No high risk air masses	—	—
Buffalo, NY	DP	—	0.5
Chicago, IL	DM	0.4	—
Cleveland, OH	MT	0.8	—
Cincinnati, OH	No high risk air masses	—	—
Columbus, OH	T	0.2	—
Dallas-Ft. Worth, TX	DP	—	1.7
	MP	—	1.0
Denver, CO	MP	0.4	—
	T	0.1	—
Detroit, MI	DP	1.1	1.6
	DM	0.8	—
Ft. Lauderdale, FL	DM	2.7	2.6
	DP	2.1	3.5
Greensboro, NC	No high risk air masses	—	—
Hartford, CT	No high risk air masses	—	—
Houston, TX	DT	2.2	—
	MP	—	1.7
	DP	—	1.1
Indianapolis, IN	MT	1.5	—
	DP	0.8	0.8
Jacksonville, FL	No high risk air masses	—	—
Kansas City, MO	DT	5.2*	0.1
	MT	2.0	1.5
Los Angeles, CA	DT	12.2*	5.1
	DP	8.4*	8.5
	MP	—	1.5
Louisville, KY	DP	0.4	0.7
	T	—	0.4
Memphis, TN	DP	1.7	—
	DM	—	0.2
	DT	—	2.0
Miami, FL	DP	7.5*	1.5
	DM	3.1	2.5
	MP	3.7	3.3
	T	—	0.5
Minneapolis, MN	No high risk air masses	—	—
Nassau County, NY	DP	—	1.2
New York, NY	MP	4.6	3.6
New Orleans, LA	DP	2.9	2.0
	MP	1.9	1.4
	T	0.5	0.8
Newark, NJ	DP	2.1	1.7
Philadelphia, PA	DP	—	3.5
Phoenix, AZ	DT	0.9	0.7
Pittsburgh, PA	DP	—	2.5
	T	1.5	1.2
Portland, OR	DP	1.3	0.9
	T	—	0.8
Providence, RI	DP	1.0	—
	MT	1.3	2.0
Riverside, CA	DP	—	0.6
	MP	—	0.6
	MT	6.2*	1.7
Salt Lake City, UT	T	0.4	0.6
San Antonio, TX	DP	1.7	1.4
San Diego, CA	DT	—	1.5
San Francisco, CA	DP	2.8	2.8
	DT	7.5*	6.1*
	MP	—	2.2
San Jose, CA	DT	3.1	3.4
Seattle, WA	DM	0.5	—
	DP	3.1	1.9
St. Louis, MO	DP	3.0	2.9
	T	1.6	—
Tampa, FL	DP	5.5*	3.7
Washington, DC	DM	0.5	0.8
	MT	—	1.3

Abbreviations. DP, dry polar; MT, moist tropical; DT, dry tropical; T, transition; MP, moist polar; DM, dry temperate; MM, moist temperate. See text for subcategories of MT.
*High risk air masses with mean excess mortality >5.0

and the range of acclimatization is likely to vary on a regional basis. Thus, unlike our previous evaluations, this study will present mortality figures that represent full acclimatization only as these constitute rather conservative estimates. In addition, for the first time we will present guidelines on how air conditioning and mortality displacement might modify these acclimatized estimates of mortality.

Results

Air mass/mortality relationships. High risk air mass categories were uncovered for a significant majority of the 44 cities, especially for summer (Tables 1, 2). Although particular high risk categories vary somewhat from one city to the next, there is clearly a high level of spatial consistency. For summer, the two hottest air masses, MT1 and DT, appear as high risk in a large majority of the cities. Of 35 cities that possessed at least one high risk air mass, MT1 was high risk in 27 cities and DT was high risk in 19. These similar responses among cities suggest that MT1 and DT air masses are often beyond a human threshold of tolerance and consistently represent conditions which impose great stress on the body. Ranking third in frequency as a high risk air mass was MT3, which is considerably drier than its MT1 counterpart.

There is some spatial homogeneity among the high risk air masses. MT1 is important in virtually all of the large cities of the East and Midwest. New York, Chicago, Philadelphia, Boston, Washington, and St. Louis are among numerous very large industrial cities where MT1 is high risk. The greatest impact of MT1 air appears to be east of the Mississippi River; of 27 cities where MT1 is high risk, only 5 are west of the river (2 of these are St. Louis and Minneapolis, located adjacent to the river). MT3 air also has its greatest impact east of the Mississippi River and is generally associated with lower mortality anomalies than MT1. The cities where MT3 air is important are all in the north central United States (Chicago, Detroit, Minneapolis, Columbus, Cleveland) or the northeastern United States (Boston, New York, Pittsburgh, Philadelphia). DT air has a dramatic impact on major cities such as New York, Philadelphia, and Chicago, but more western cities seem affected by this air mass, especially in the Southwest. Half of the cities where DT air is high risk are west of the Mississippi River, including all the important Texas cities in this study (MT1 is not a significant mortality factor in these cities).

The DT and MT air masses create different stresses on the body. MT air, with its relatively high humidity, lessens the body's ability to increase evaporative heat loss by perspiration and vasodilatation (*30*). Latent heat loss from the body (which is necessary to maintain a body core temperature within a narrow range) is partially dependent upon the rate of perspiration evaporation; high humidities decrease vapor pressure gradients, which are directly proportional to evaporation rate (*31*). Thus, the rate of perspiration evaporation is diminished during MT episodes as humidity gradients beween the body and atmosphere are diminished. During dry DT episodes vapor pressure gradients are sufficiently high, but desiccating conditions increase evaporation opportunity to such a level that perspiration production is insufficient; hypothermal conditions may then result in death (*32,33*).

In most cities where both MT1 and DT air masses are considered high risk, DT is associated with the higher mortality anomalies. For example, the mean excess mortality in New York City associated with MT1 is about 30 deaths; for DT, this value approaches 50 (Table 1). Considering population differences, variation from baseline mortality for DT air is even greater in Philadelphia, St. Louis, and Pittsburgh. However, it is noteworthy that DT air occurs on less than 2% of summer days east of a line from Minneapolis to Birmingham. Conversely, the three MT air masses occur on over 50% of summer days south of Memphis and Atlanta and on more than 25% of the summer days south of Chicago and New York (*24*). Although DT air is associated with very high excess mortality values, it is very rare in the eastern United States.

In a few cases, certain counter-intuitive summer air masses appear as significant in impacting human mortality. For example, there is a relationship between Atlanta DP and total mortality and Tampa MM and total mortality. It is possible that a few spurious relationships will be uncovered using an empirical analysis such as the one presented here. However, for summer mortality relationships, we are quite impressed with the dominance of DT air and MT1 air in most cities where weather has a significant impact on mortality; it can be strongly suggested that these relationships are truly important.

As was demonstrated in previous research (*9,14*), many cities in the South and on the West Coast show weak weather/mortality relationships in summer. Of eight cities with no high risk summer air masses, three are in Florida and three are in California. Other southern cities that are associated with high risk air masses show weaker relationships than northern counterparts; excess mortality values are relatively low for New Orleans, Birmingham, and Atlanta. There is speculation that urban housing amenable to hot weather in southern cities renders them less vulnerable to heat-related mortality (*22*).

Determination of winter high risk air masses is more difficult, and mortality increases are less dramatic within these air masses. However, there is evidence that the cold, dry DP air masses increase winter mortality slightly in a number of cities, although the spatial continuity is relatively poor (Table 2). There is no locale where DP air is associated with more than 10 deaths above the baseline; these values are much lower than the excess deaths associated with MT1 and DT air in summer, especially within the large midwestern and eastern cities. Most winter DP mortality increases range from one to three extra deaths per day, with Miami exhibiting the highest total of 7.5. Interestingly, DP air appears unimportant in most of the cities where summer high risk air masses were found. For Chicago, New York City, and Boston, DP is not a high risk air mass. For Philadelphia and St. Louis, DP air contributes to slightly elevated mortality, but only represents about three extra deaths in both cities. Cool, damp MP air appears important in New York City (only associated with 4.6 deaths above the baseline), Miami, and New Orleans, and transition situations lead to slightly elevated mortality in a few scattered cities.

Some other air masses, including warm ones, appear to be high risk during winter in certain cities. For example, warm, dry DT air surprisingly contributes to some excess winter mortality in the Southwest and on the West Coast (DT temperatures can get very warm, even in winter). Some of the most dramatic winter anomalies are associated with this warm air mass, as indicated by Los Angeles (12.2 excess deaths), San Francisco (7.5 excess deaths), and San Jose (3.1 excess deaths). Considering this warm-weather winter effect, the potential impact of warmer winter temperatures on mortality is much less clear-cut, but appears unlikely to offset large summer increases.

Unlike the summer results, it is much more probable that a larger proportion of air mass/mortality relationships uncovered for winter are spurious. Although there is some indication that DP air is associated with higher winter mortality, the spatial consistency of its impact is much less than MT1 or DT air masses during summer. The location of cities possessing no high risk air masses is not nearly as systematic as in summer. Thus, the role of weather on winter mortality appears to be much more indirect, possibly attributed to causes (such as indoor confinement) that are not readily apparent using an air mass analysis or any other meteorological procedures.

These results generally support our earlier work on winter mortality, which indicates that threshold meteorological conditions leading to higher mortality are either nonexistent or difficult to find (*14*). In addition, the coldest air mass is only associated with slightly increasing mortality. A number of winter studies in Europe seem to suggest that colder temperatures lead to higher mortality, but even some of these have had difficulty in determining specific threshold conditions similar to those found in summer (*5*). However, it is clear that there are differences in findings relating to weather/winter mortality between European and U.S. studies, and more collaborative research in this area is necessary. Professor W.R. Keatinge of the University of London Department of Physiology is attempting to gather experts from around the world to discuss the winter mortality question, and the results of this conference will be forthcoming.

The impact of climate change. The GCM scenarios suggest major changes in the frequencies of high-risk air mass categories, especially in summer (Table 3). For example, MT1 presently occurs on about 5% of days during an average summer in New York. The most conservative scenario (GFDL 2020) shows a doubling in frequency, and others suggest that this air mass will occur up to six times more frequently (UKMO 2050). The DT air mass shows similar increases in New York. Considering that, on a typical DT day, mortality is almost 50 deaths above the baseline level in New York, such increases could be devastating on mortality rates. Similar magnitude increases in summer high-risk air masses are noted for virtually all of the large midwestern and eastern cities where weather/mortality relationships are so strong.

Using the high-risk air mass algorithms and the acclimatization procedure discussed earlier, mortality estimates were developed for summer and winter for the six GCM scenarios (Tables 4 and 5). Results suggest that summer mortality will increase considerably for cities where high risk summer air masses were found. For example, during a present-day typical summer, it is estimated that 1,840 excess deaths occur due to the presence of high-risk air masses. These values increase under the three 2020 GCM scenarios. The GFDL scenario shows an increase of less than 10%, but the UKMO and Max Planck scenarios estimate much more dramatic increases (over 4,000 excess deaths and 2,800 excess deaths, respectively). Cities such as New York, Philadelphia, Chicago, and Detroit appear most vulnerable, especially if the UKMO scenario is used. For New York, excess mortality increases from the present 307 deaths to over 750 under the UKMO 2020 scenario.

Table 3. General circulation model estimates of summer air mass frequencies for selected cities

		2020 climate			2050 climate		
City/air mass	Present climate	GFDL 89	UKMO	Max Planck	GFDL 89	UKMO	Max Planck
Chicago							
MP	5.00	3.01	0.87	1.92	1.67	0.87	1.52
DP	10.20	5.47	2.28	3.91	3.33	2.28	2.72
DT	1.80	3.23	7.54	5.58	4.82	9.06	7.94
DM	29.40	30.26	21.20	24.47	26.86	18.92	20.08
MM	13.40	13.08	10.55	10.98	12.07	9.68	9.75
MT1	5.20	10.76	30.26	23.67	18.90	33.16	31.42
MT2	7.90	4.86	1.96	2.97	3.91	1.63	1.88
MT3	15.50	17.33	13.16	14.46	16.85	11.82	12.03
T	11.60	11.24	10.95	11.16	11.42	11.42	11.49
New York							
MP	7.90	4.72	2.21	4.32	2.29	1.85	3.19
DP	2.70	1.60	0.73	1.34	0.76	0.65	0.98
DT	1.30	2.03	4.10	2.61	3.45	6.03	4.07
DM	24.60	21.52	15.06	18.95	16.66	11.76	15.61
MM	25.60	23.59	19.27	21.31	20.33	16.66	19.56
MT1	4.90	10.74	24.03	15.90	21.78	30.56	23.12
MT2	5.60	4.50	3.12	4.10	3.01	2.58	2.69
MT3	11.20	13.32	12.41	13.10	12.67	10.71	11.76
T	16.50	17.64	18.11	17.75	18.26	18.19	18.04
Los Angeles							
MP	14.20	9.60	24.54	6.02	17.14	31.06	11.92
DP	16.80	3.52	3.01	6.38	0.83	1.41	2.54
DT	0.00	24.03	15.15	23.41	20.91	13.95	22.80
DM	16.90	44.29	37.59	42.55	43.93	36.39	44.76
MM	33.10	2.97	2.94	5.91	0.40	0.91	2.28
MT1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MT2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MT3	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T	16.50	15.59	16.78	15.73	16.78	16.27	15.69

Abbreviations: GFDL, Geophysical Fluid Dynamics Laboratory; UKMO, United Kingdom Meteorological Office; MP, moist polar; DP, dry polar; DT, dry tropical; DM, dry temperate; MM, moist temperate; MT, moist tropical; T, transition. See text for subcategories of MT.

The 2050 scenarios paint an even bleaker picture. The relatively conservative GFDL scenario indicates a summer mortality increase of over 70% for the cities used in this study. Mortality estimates using the UKMO and Max Planck 2050 scenarios are more than double present-day values. As was the case with the 2020 scenarios, the large eastern and midwestern cities appear most vulnerable. For New York City, summer mortality estimates are more than triple present values using the UKMO scenario. Similar increases are estimated for Philadelphia, Chicago, Minneapolis, and Detroit.

One of the most disputed questions is whether winter mortality decreases will offset these large summer increases. This study suggests that this will not be the case (Table 5). At present, slightly over 1,000 excess deaths are attributed to high risk air masses for the 44-city sample during winter. Of course, winter mortality is generally higher than summer, but variation in meteorology appears not to be the responsible agent. Previous studies indicate that prevalence of infectious and respiratory diseases, which are largely responsible for the higher winter mortality, is not correlated well with winter temperature (*2*). Repeated attempts to correlate annual outbreaks of winter diseases such as influenza with monthly winter temperatures have been unsuccessful (*18,20*). Thus, meteorological variation has little impact on the increased baseline in deaths that occur in winter, but does contribute to the 1,000 excess deaths associated with the high-risk air masses.

Surprisingly, application of the GCM scenarios to estimate winter mortality shows little change from present conditions. Using the 2020 scenarios, winter mortality is about the same as that for the GFDL and Max Planck GCMs and slightly lower for the UKMO scenario. All three 2050 scenarios yield a slight drop in winter mortality, especially for the UKMO GCM, where a decrease from the present of about 15% is noted. However, the 100–200 death drop in winter mortality is much less than the large increases of 1,300 to almost 3,000

Table 4. Estimated total excess mortality for an average summer season, assuming full acclimatization

		2020 climate			2050 climate		
SMSA	Present climate	GFDL 89	UKMO	Max Planck	GFDL 89	UKMO	Max Planck
Anaheim	0	0	0	0	0	0	0
Atlanta	25	43	62	22	60	138	33
Baltimore	84	57	148	63	124	164	131
Birmingham	42	26	47	14	40	47	21
Boston	96	113	165	134	155	194	160
Buffalo	33	15	52	36	34	73	59
Chicago	191	243	538	421	359	583	550
Cincinnati	14	16	90	49	54	81	67
Cleveland	29	21	55	44	46	58	53
Columbus	33	24	83	51	51	90	78
Dallas	36	45	62	45	107	64	44
Denver	42	29	41	30	35	39	32
Detroit	110	84	240	164	130	271	256
Ft. Lauderdale	0	0	0	0	0	0	0
Greensboro	22	28	43	27	37	45	29
Hartford	38	21	42	32	38	50	41
Houston	7	7	16	7	15	17	6
Indianapolis	36	23	93	51	55	86	69
Jacksonville	0	0	0	0	0	0	0
Kansas City	49	79	173	93	121	156	105
Los Angeles	68	74	123	83	110	128	116
Louisville	17	0	2	0	0	1	1
Memphis	25	42	27	57	40	29	49
Miami	0	0	0	0	0	0	0
Minneapolis	59	55	185	148	123	215	186
Nassau	29	59	84	84	110	116	116
New Orleans	20	0	0	0	0	0	0
New York	307	363	753	498	460	999	727
Newark	26	83	173	111	150	127	161
Philadelphia	129	99	362	191	246	477	323
Phoenix	0	0	0	0	0	0	0
Pittsburgh	39	32	66	64	61	83	95
Portland	9	13	22	11	23	31	14
Providence	47	39	80	52	73	96	74
Riverside	4	6	10	6	8	11	7
Salt Lake City	0	0	0	0	0	0	0
San Antonio	4	0	0	0	0	0	0
San Diego	0	0	0	0	0	0	0
San Francisco	28	24	23	23	18	24	23
San Jose	0	0	0	0	0	0	0
Seattle	5	1	0	2	0	0	1
St. Louis	79	149	173	158	212	155	189
Tampa	28	68	95	28	95	100	47
Washington, DC	0	0	0	0	0	0	0
Total	1,840	1,981	4,128	2,799	3,190	4,748	3,863

Abbreviations: SMSA, standard metropolitan statistical area; GFDL, Geophysical Fluid Dynamics Laboratory, UKMO, United Kingdom Meteorological Office. Values given are estimated deaths.

deaths in summer mortality under the 2050 scenarios. The lack of a more significant winter drop is possibly attributed to the weak winter/mortality relationships within the high-risk categories. There is much less variation in mortality around the baseline within the winter categories when compared to high-risk summer categories. Thus, even though the GCMs suggest decreases in the frequencies of cold winter high-risk categories, the concomitant decreases in mortality are not very large. In addition, some of the winter high-risk categories are not the coldest and will not necessarily decrease in frequency if the climate warms. For example, the high-risk category for New York City is MP, which is not particularly cold. MP frequencies are estimated to increase under the various climate change scenarios. MP currently occurs on about 25% of winter days presently in New York; the GCMs point to increases of about 33% using 2050 scenarios. For Los Angeles, the high-risk category with the greatest mortality excess in winter is DT. This category will increase in frequency from the present 5% to about 9% during warmer winters, and this is reflected in the minimal mortality change in Los Angeles mortality as estimated by the GCMs (Table 5).

Two socioeconomic factors complicate the impact of climate change on mortality. The first, air conditioning, may result in reduced summer mortality if use becomes more widespread. The second, mortality displacement, suggests that some of the deaths attributed to heat and cold might be individuals who would have died shortly afterward regardless of the weather.

In an attempt to determine if air conditioning will be a mitigating factor, a recent study has compared mortality totals in several cities over a 25-year period in which access to air conditioning increased strikingly (*2*). The proportion of U.S. urban homes with air conditioning increased rapidly during this period; for example, in St. Louis, estimates indicate a rise in air conditioning in 40% of homes in 1965 to 91% in 1992. Air conditioning saturation (where virtually 100% of homes have air conditioning) is expected in most major U.S. urban areas by the early twenty-first century (Stern et al., unpublished data). The study suggests that, for New York City, approximately a 21% reduction in heat-related deaths may have occurred from 1964 to 1988 because of increased access to air conditioning (*22*). It is suggested in the study that other vulnerable U.S. cities may have experienced similar reductions, and these findings imply that air conditioning saturation in the twenty-first century could reduce somewhat the heat-related mortality totals presented in Table 4 (*2*). However, the degree of mitigation offered by air conditioning in a warmer world is difficult to quantify, and no study has, as of yet, developed estimates of the possible reduction of future heat-related deaths attributed to air conditioning.

The question of mortality displacement has been discussed more fully, and it has been demonstrated that a proportion of people who die during heat waves would have died shortly afterward, regardless of weather. In addition, it has been suggested that the impact of successive heat waves within a single season is likely to be subject to the effects of progressive selection and adaptation (*2*). Studies suggest that the proportion of deaths during a heat wave that represent short-term mortality displacement varies between about 20 and 40% (*22*). For a given city, displacement proportions seem rather consistent, with 20% values determined for two heat waves in St. Louis, and 40% values for three heat waves in New York City. There is reason to believe that these figures would be representative even in a warmer world, and the acclimatized mortality estimates presented in Table 4 could be reduced by 20–40%. However, even if this is the case, these studies indicate that a majority of heat-related deaths are not simply short-term displacements, but represent individuals who would otherwise not have died shortly after the heatwave. Thus, even when air

Table 5. Estimated total excess mortality for an average winter season, assuming full acclimatization

SMSA	Present climate	2020 climate GFDL 89	2020 climate UKMO	2020 climate Max Planck	2050 climate GFDL 89	2050 climate UKMO	2050 climate Max Planck
Anaheim	2	0	0	1	0	0	0
Atlanta	37	53	48	52	50	47	52
Baltimore	0	0	0	0	0	0	0
Birmingham	25	12	8	11	11	7	12
Boston	0	0	0	0	0	0	0
Buffalo	7	18	8	17	5	5	18
Chicago	2	4	3	4	4	2	5
Cincinnati	0	0	0	0	0	0	0
Cleveland	2	9	10	10	15	10	9
Columbus	12	1	2	1	3	2	1
Dallas	32	41	33	43	36	31	41
Denver	9	10	11	10	11	11	11
Detroit	34	15	20	15	18	26	14
Ft. Lauderdale	36	4	4	5	3	3	5
Greensboro	0	0	0	0	0	0	0
Hartford	0	0	0	0	0	0	0
Houston	24	33	29	35	29	27	33
Indianapolis	16	32	28	33	34	28	32
Jacksonville	0	0	0	0	0	0	0
Kansas City	12	51	36	46	42	35	46
Los Angeles	100	102	78	100	77	88	81
Louisville	16	12	17	12	19	15	12
Memphis	23	20	17	19	19	15	19
Miami	46	35	35	37	32	32	36
Minneapolis	0	0	0	0	0	0	0
Nassau	24	21	4	20	5	3	21
New Orleans	52	56	51	54	51	47	54
New York	102	123	150	120	152	93	121
Newark	48	23	8	20	10	6	23
Philadelphia	85	80	14	73	36	9	82
Phoenix	26	25	26	25	26	27	26
Pittsburgh	19	20	29	21	24	31	21
Portland	17	15	12	15	12	10	13
Providence	27	21	34	33	35	36	21
Riverside	10	26	29	26	27	27	26
Salt Lake City	5	7	9	8	8	10	9
San Antonio	9	10	6	11	5	4	9
San Diego	17	26	16	24	16	18	16
San Francisco	85	39	30	42	30	21	26
San Jose	3	2	4	2	3	5	4
Seattle	13	40	45	37	46	47	43
St. Louis	50	61	68	60	53	61	61
Tampa	21	26	24	26	22	20	25
Washington, DC	19	31	38	30	20	35	31
Total	1,067	1,104	984	1,098	989	894	1,059

Abbreviations: SMSA, standard metropolitan statistical area; GFDL, Geophysical Fluid Dynamics Laboratory, UKMO, United Kingdom Meteorological Office. Values given are estimated deaths.

conditioning mitigation and displacement are considered, heat-related mortality should nevertheless increase substantially in a warmer world. The estimates presented in Table 4 should be deemed conservative, as they assume full acclimatization, and the increases are generally substantially greater than the combined estimated reduction offered by air conditioning and mortality displacement.

Conclusions

The objective of this paper was to utilize a new air mass-based synoptic procedure to evaluate climate/mortality relationships as they presently exist and to estimate how climate change, as suggested by IPCC-applied GCMs, might alter these values. Forty-four cities with SMSA populations exceeding 1 million were analyzed in this study. The following are some of the most salient results.

- During summer, two air masses consistently appear as high-risk: hot, dry DT and very warm, humid MT1. The latter is most important in the large eastern and midwestern cities, while the former impacts western cities as well. In some cases, average daily mortality increases by over 15 when these air masses are present.
- Many cities in the South and Southwest show weaker summer weather/mortality relationships than their eastern and midwestern counterparts. This supports earlier research and is probably attributed to acclimatization to less variable summer weather and differences in urban structure between regions.
- Winter high-risk air masses are more difficult to discern, and variation from the baseline is much less. The greater winter mortality (when compared to summer) is primarily attributed to causes of death that do not vary much with ambient temperature; thus, the coldest winter days are not associated with mortality spikes that are present during summer.
- High-risk winter air masses include cold, dry DP, but warm, dry DT is associated with high winter mortality in the West, and moist MP contributes to greater deaths in some large eastern and southern cities. However, the spatial consistency of high-risk air masses is much worse than summer, and some of these winter relationships may be spurious.
- GCM scenarios suggest that great increases in frequency of summer high-risk air masses could contribute to significantly higher summer mortality, especially for the 2050 models. Increases using 2050 models range from 70% for the most conservative GCM to over 100% for the other GCMs, even if the population acclimatizes to the increased warmth.
- The scenarios suggest that winter mortality will drop slightly, but will not offset summer increases to any significant degree. This is attributed to weaker weather–mortality relationships during winter and to the fact that many high-risk winter air masses are not the coldest and thus will not decrease in frequency if climate change occurs.
- The impact of air conditioning mitigation and mortality displacement may reduce somewhat the above estimates. However, the number of present-day heat-related deaths in U.S. cities is still considerable in spite of these mitigating factors, even in cities where air conditioning is presently found in more than 90% of the households. Thus, we suggest that the combined impacts of these factors will only partially offset the very large increases estimated by the GCMs, and a substantial rise in weather-related mortality is the most likely outcome of a global warming.

There is a need for additional research to sharpen these estimates and to further comprehend the impact of extreme heat and cold on human mortality. Considerable work is in progress relating to the impact of air conditioning and mortality displacement in altering the estimates provided here. In addition, work is in progress to assess the possibly synergistic role of air pollution and extreme weather on mortality (*2*).

As suggested by the IPCC Working Group II (*1*), this research suggests the need for improved health impact assessment capability, including local monitoring systems for the early detection of climate-induced changes on human health. Regardless of whether the climate changes, this work underscores the importance of developing more sophisticated watch/warning systems so urban areas can reduce the risk of heat-related deaths and minimize the possibility of a tragedy similar to that which occurred in Chicago during the summer of 1995 (*34*). As stated in the recent National Disaster Survey Report (*35*), extreme heat may be one of the most underrated of the deadly weather phenomena, and timely warnings are of utmost importance to provide city officials with information necessary for the development of proper mitigating actions.

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Q23. On page 14 of your written testimony you state the following:

"Climate change is likely to extend the geographic ranges and increase the rates of transmission of disease-carrying vectors such as mosquitoes, which can increase the populations exposed to diseases such as malaria, dengue and yellow fever. Globally, the population exposed to malaria could increase by one-third. There could be 50-80 million additional malaria cases per year, assuming no change in public health protection."

Please document these statements.

A23. Chapter 18 ("Human Population Health") of the 1995 IPCC document *Climate Change 1995 - Impacts, Adaptations and Mitigation of Climate change: Scientific-Technical Analyses* provides an up-to-date summary of what is known on the potential human health impacts of climate change. The overall conclusion of this chapter is that most of the impacts would be adverse. Some would occur via direct pathways (e.g., deaths from heat waves and extreme weather events), while others would occur indirectly (e.g., due to changes in the range of vector-borne diseases. Populations with different levels of natural, technical, and social resources would differ in their vulnerability to climate-induced health impacts. Crowding, food insecurity, local environmental degradation, and disturbed ecosystems already exist in many developing countries and would all increase vulnerability. A copy of this chapter of the document was attached in response to Q21 above.

Q24. On page 14 of your written testimony you state the following:

"Climate change can reduce air quality and increase levels of air borne pollen and spores, which exacerbate respiratory disease, asthma, and allergic disorders."

Please document these statements.

A24. Research has shown that ground level ozone, the primary constituent of smog, is affected by weather and climate, and that there is a strong positive relationship between ozone concentrations and temperatures (see The *Regional Impacts of Climate Change: An Assessment of Vulnerability*, IPCC, 1998, pages 310-311, attached). The potential effects of climate change on the production of plant allergens are also discussed in that report. Other sources on the relationship between weather and air quality include: *Rethinking the Ozone Problem in Urban and Regional Air Pollution*, (National Research Council, National Academy Press, Washington, DC. Dec 1991); *National Air Quality and Emissions Trends Report, 1995* (EPA 454/R-96-005); *The Potential Effects of Global Climate Change on the United States, Report to Congress, Appendix F: Air Quality* (EPA-230-05-89-056); "Preliminary assessment of the effects of global climate change on tropospheric ozone concentrations" (paper presented at the American Waste Management Association Specialty Conference: *Tropospheric Ozone and the Environment II*, November 1991); "Photochemical modeling analysis under global warming conditions" (AWMA paper No. 95-WP74B.02, presented at the AWMA annual meeting, San Antonio, 1995); "The effects of climate change" in *Global Climate Change Linkages: Acid Rain, Air Quality, and Stratospheric Ozone* (ed. J. C. White. New York: Elsevier. 1989); and "Sensitivity of tropospheric oxidants to global chemical and climate change," *Atmospheric Environment* 23:519-532.

<u>**Impacts on Water Resources**</u>

Q25. On page 14 of your written testimony you also state the following:

"Water Resources: Among the most fundamental effects of climate change is an intensification of the hydrological cycle. Changes in precipitation, and increased evaporation and transpiration due to higher temperatures, can be expected to reduce water runoff, affecting the quantity and quality of water supplies for domestic and industrial uses, irrigation, hydropower generation, navigation, stream ecosystems and water based recreation. These effects will vary region by region. Increased variability in the hydrologic cycle is expected to result in more severe droughts and/or floods in some places. Impacts and mitigation expenses for such events are significant; damage estimates from the Mississippi flood of 1993 range from $10 billion to $20 billion. Areas of greatest vulnerability are those where water supplies and quality are already problems, such as arid and semi-arid regions of the world and some low lying coastal areas, deltas and small islands.

- **Climate change would likely add to the stress in several U.S. river basins, such as the Great Basin, California, Missouri, Arkansas, Texas Gulf, Rio Grande, and Lower Colorado.**

- **The Colorado River Basin would suffer decreased summer runoff, coinciding with peak demand for irrigation, unless precipitation also increases substantially. Reductions in runoff of up to 25 percent in the basin are projected under some scenarios.**

- **Water scarcity in Middle Eastern and African countries also is likely to be exacerbated by climate change. Countries that are highly dependent on water originating in areas outside their borders include Syria, Sudan, Egypt and Iraq."**

Please document these statements.

A25. Chapter 14 of the document *Climate Change 1995 – Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses* provides a recent evaluation of potential climate change impacts to water resources. Its principal conclusions are that:

- Most regional water resources systems in the 21st century, particularly in developing countries, will become increasingly stressed due to higher demand to meet the needs of growing populations and economies and protect ecosystems.
- Arid and semi-arid watersheds and river basins are the most sensitive to changes in temperature and precipitation.
- Water demand for irrigated agriculture is very sensitive to climate change, especially for arid and semi-arid regions,
- Current models cannot provide watershed-specific information to allow robust estimates regarding changes in water availability.
- The primary components for increasing flexibility of water resources systems to meet increasing uncertainties due to climate change are water demand management and institutional adaptation.
- Increased streamflow regulation and water management regimes may be necessary to enable water systems to meet their goals.
- Isolated single reservoirs are less adaptable to climate change than integrated multiple-reservoir systems.

A copy of this chapter of the document is attached.

14

Water Resources Management

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CONTENTS

EXECUTIVE SUMMARY

Water availability is an essential component of welfare and productivity. Much of the world's agriculture, hydroelectric power production, municipal and industrial water needs, water pollution control, and inland navigation is dependent on the natural endowment of surface and groundwater resources. Changes in the natural system availability would result in impacts that generally are greatest in regions that are already under stress, including currently arid and semi-arid areas, as well as areas where there is considerable competition among users. The purpose of water resources management is to ameliorate the effects of extremes in climate variability and provide a reliable source of water for multiple societal purposes. This evaluation of climate-change impacts focuses on the expected range of changes in the hydrological resources base and the sensitivity of the water supply and water demand components of the water management systems to climate change. It also makes an assessment of the viability of adaptive water management measures in responding to these impacts.

There are reasons for water resources managers, especially in developing nations, to be concerned by the results of climate-change scenarios, which show that the freshwater resources in many regions of the world are likely to be significantly affected. In particular, current arid and semi-arid areas of the world could experience large decreases in runoff—hence posing a great challenge to water resources management. Global-change-induced perturbations may follow widespread periodic and chronic shortfalls in those same areas caused by population growth, urbanization, agricultural expansion, and industrial development that are expected to manifest themselves before the year 2020 (High Confidence).

Uncertainties require considerable investment in research in order to improve prediction and adaptive responses. Some uncertainties in assessing the effects of climate change on water resources are:

- Uncertainties in general circulation models (GCMs) and lack of regional specification of locations where consequences will occur
- Insufficient knowledge on future climate variability, which is a basic element of water management
- Uncertainties in estimating changes in basin water budgets due to changes in vegetation and in atmospheric and other conditions likely to exist 50 to 100 years from now
- Uncertainties in future demands by each water sector
- Uncertainties in the socioeconomic and environmental impacts of response measures.

Hence, predicting where water resources problems due to climate change will occur can only be realized on a subcontinental scale at this time. However, water management decisions are made on the localized, watershed scale. Therefore, despite increases in the number of impact assessments and improvements in the new class of transient GCMs, there is little that can be added to the conclusions of the first two IPCC reports on the subject, other than to note the regions and countries most likely to be vulnerable through a combination of increased demands and reductions in available supplies. However, one important addition is the limited but growing analyses of water systems in the developing world. These limited studies seem to suggest that developing countries are highly vulnerable to climate change because many are located in arid and semi-arid regions and most existing water resources systems in these countries are characterized as isolated reservoir systems. Also, there is more evidence that flooding is likely to become a larger problem in many temperate regions, requiring adaptations not only to droughts and chronic water shortages but also to floods and associated damages and raising concerns about dam and levee failures (Medium Confidence).

Water management is a continuously adaptive enterprise, responding to changes in demands, hydrological information, technologies, the structure of the economy, and society's perspectives on the economy and the environment. This adaptation employs four broad interrelated approaches: new investments for capacity expansion; operation of existing systems for optimal use (instream and offstream); maintenance and rehabilitation of systems; and modifications in processes and demands (e.g., conservation, pricing, and institutions). These water management practices, which are intended to serve the present range of climate variability (which in itself is considerable), may also serve to ameliorate the range of perturbations such as droughts that are expected to accompany climate change. However, adaptations come at some social, economic, and environmental costs.

Most of the standard water resources performance criteria—such as reliability, safe yield, probable maximum flood, resilience, and robustness—are applicable in dealing with the impacts of climate change on water resources systems. This is not to suggest that we can become complacent in our response to climate change. The emphasis of water resources management in the next decades will be on responses to increased demands, largely for municipal water supply in rapidly urbanizing areas, energy production, and agricultural water supply. Water management strategies will focus on

demand management, regulatory controls, legal and institutional changes, and economic instruments. The principal conclusions are as follows:

- Most of the regional water resources systems in the 21st century, particularly in developing countries, will become increasingly stressed due to higher demand to meet the needs of a growing population and economy, as well as to protect ecosystems (High Confidence).
- Arid and semi-arid watersheds and river basins are inherently the most sensitive to changes in temperature and precipitation (High Confidence).
- Water demand for irrigated agriculture is very sensitive to climate change, especially in arid and semi-arid regions (High Confidence).
- The current generation of transient GCMs, though much improved, does not offer the degree of watershed-specific information or anticipated variability in future climate required to allow robust estimates to be made regarding changes in water availability (High Confidence).
- Water demand management and institutional adaptation are the primary components for increasing the flexibility of water resources systems to meet increasing uncertainties due to climate change (High Confidence).
- Increased streamflow regulation and water management regimes may be necessary to enable water systems to meet their goals (High Confidence).
- Isolated single-reservoir systems are less adaptable to climate change than integrated multiple-reservoir systems (High Confidence).
- Technological innovations and cost-effective technologies have already played a major role in water management; likely future technological changes can serve to mitigate many of the consequences of climate change (Medium Confidence).
- Changes in the mean and variability of water supply will require a systematic reexamination of engineering design criteria, operating rules, contingency plans, and water allocation policies (Medium Confidence).
- Temporal streamflow characteristics appear to be more variable under future climate scenarios, and amplification of extremes appears likely (Low Confidence).

14.1. Introduction

14.1.1. Objectives

Water resources are an important aspect of the world's social, economic, and ecological systems. Agriculture, hydroelectric power production, municipal and industrial water demands, water pollution control, and inland navigation are all dependent on the natural endowment of surface and groundwater resources. Civilizations have flourished and fallen as a consequence of regional climatic changes, and many "hydraulic civilizations" were formed around the need to control river flow. This endowment is not evenly distributed spatially or temporally. With the imbalance of water supply and demand, many nations are in water-scarce situations and face water crises at a local level. From 1940 to 1987, global water withdrawals increased 210%, while the world's population increased by 117% (Gleick, 1993; Shiklomanov, 1993). A global water resources assessment for the year 2025 (Strzepek *et al.*, 1995) suggests that for the United Nations median population forecast of 8.5 billion (a 55% increase over 1990) and a globally balanced economic growth path, global water use may increase by 70%.

The potential for the world to face a water-stressed condition in 2025 under population and economic growth makes assessment of possible water resource impacts associated with climate change an essential component of the IPCC assessment. Changes in hydrological processes are discussed in Chapter 10. This chapter examines the impact on water supply and use and evaluates possible water management response strategies. Water resources management is the interaction of technology, economics, and institutions for the purpose of balancing water supply with water demand and coping with hazards associated with hydrological extremes. The goal of this chapter is to provide an understanding of the sensitivity of the components of water resources systems to potential climate change. Because the water management process occurs at local and regional levels, this chapter cannot provide an assessment of global or continental impacts of climate change; however, it will glean from available literature the sensitivities of various water systems to increases and decreases in river runoff and examine changes in water demands due to changes in regional climate. Because changes in water use will affect many sectors of society and the economy, other chapters in this volume are referenced, such as those addressing wetlands, coastal zones and small islands, energy supply, transportation, human settlements, agriculture and forestry, fisheries, health problems, and financial services.

The main message of this chapter is that climate change will impact the water resources systems of the world but that we will be able to adapt—though at some cost economically, socially, and ecologically. Some analysts (Rogers, 1993a, 1993b; Klemes, 1993; Stakhiv, 1994) feel that current systems will respond well and costs will be minimal; others feel that adaptation will be difficult and in some cases extremely costly. The reason for this disparity is that the sensitivities, impacts, and costs are nonuniformly distributed across the globe. Most analyses have been conducted for regions in the developed world. The limited case studies implemented on river basins in developing countries show that sensitivities, impacts, and costs may be high. Also, much more research is needed on the response of water demands to climate change, especially nonwithdrawal uses such as recreation, fisheries, wetlands, ecosystems, and waterfowl protection.

14.1.2. An Overview of Assessment Issues and Concepts

The two previous IPCC assessments outlined the extensive difficulties in conducting meaningful analyses of climate-change impacts on hydrology and water resources (Shiklomanov *et al.*, 1990; Stakhiv *et al.*, 1992). Since then, many studies have been conducted in different basins—almost exclusively in developed countries—but the general conclusions of the earlier IPCC assessments have not changed. The uncertainties of climate-change impact analysis, especially at the catchment scale, remain large.

It is necessary to distinguish between the physical effects of climate change—which are reviewed in Chapter 10—and the impacts, which reflect a societal value placed on a change in some physical quantity. The impact depends largely on the characteristics of the water-use system: In some cases, a large climate-change effect may have a small impact; in others, a small change may have a large impact.

There are many different types of water supply systems in operation in the world. The simplest "system" extracts water from a local stream or village borehole; this is characteristic for most of the developing world and rural areas in many developed countries. Such supply systems, with no storage, are potentially very sensitive to climate change. The next system level consists of a single managed source—which may be a river, reservoir, or aquifer—coupled with a distribution network to provide water to users and possibly also to treat wastes and return effluents to the river. The sensitivity of such a system to climate change will depend on its characteristics—for example, on the storage-to-runoff ratio and on the seasonal distribution of water supply and demand. The most sophisticated systems are integrated networks, comprising several sources and possibly involving the transfer of water over large distances. Such systems usually are found only in developed countries; their sensitivity to climate change will depend on system structure and the degree of utilization.

Most water managers, whether they are with agencies dealing with multiple-reservoir systems or with small utilities dependent on groundwater, are concerned with three issues: new investments for capacity expansion; the operation and maintenance of existing systems; and modifications in water demand (Rogers, 1993b). Most developed countries have completed major capital-intensive developments of water resources infrastructure. Water managers in those countries operate under conditions of stable population and increased pressure for the incorporation of environmental protection objectives into the operation of existing water resources systems. The main issue they face is reallocation of existing water among competing uses. This requires continuous adaptation driven by new hydrologic information, ecological constraints, water-quality standards, and shifts in demands and preferences. Water-supply entities also may wish to explicitly or implicitly reconsider the level of service delivered. Institutional adaptation—consisting of changes in organizations, laws, regulations, and tax codes—may be the most effective means for aligning water demands with available supplies (Frederick, 1993; Rogers and Lydon, 1994; World Bank, 1994). This situation is a reality for managed water systems but less so for unmanaged systems (e.g., wetlands) dependent entirely on river flow, groundwater level, or precipitation. Water managers in developing countries are facing population growth-driven increases in water demands, and these demands are met primarily by increasing the water supply via capital-intensive investments to develop infrastructure. With planning and construction times of 20 to 30 years or more for major water projects, the question asked by many water resources managers in developing countries (Riebsame *et al.*, 1995) is how climate change might impact the design of new water resource infrastructure.

14.2. Impact of Climate on Water Supply

14.2.1. Introduction

Climate change is likely to have an impact on both the supply of and demands for water. This section focuses on the supply of water, looking at the river catchment scale, the global and regional context, and water quality; Section 14.3 considers impacts on demands. Most climate-change impact studies have taken the form of sensitivity analyses by feeding climate-change scenarios into hydrological models. The outputs of these studies tend to be expressed in terms of changes in the reliable yield of the systems, changes in the volume of water that can be supplied, or changes in the risk of system failure. Virtually all of the studies have simulated what would happen in the absence of adaptation to change. In practice, however, water management authorities will adapt using existing or new management options—as shown to be feasible in the Great Lakes region by Chao *et al.* (1994) and Hobbs *et al.* (1995)—although such adaptation may incur added costs and involve tradeoffs that result in reductions in service for some water users. Only a few studies (Riebsame *et al.*, 1995; Strzepek *et al.*, 1995) have considered factors other than climate change that might affect water resources over the next few decades, such as population growth, economic development, and urbanization.

There are several possible effects of global warming on the amount of water available within a catchment or water supply area; these are summarized in Table 14-1. The relative importance of each characteristic varies considerably among catchments, depending not only on the hydrological change but also on the characteristics of the supply system. For example, a conjunctive-use system involving several reservoirs, river regulation, and groundwater boreholes will be affected differently than a supply system based on direct abstractions from an unregulated river.

Table 14-1: Summary of effects of global warming on water supply.

Effect of Global Warming	Impact on Water Supply Reliability
Change in river runoff	Yield in direct water abstraction Yield in reservoir systems
Change in groundwater recharge	Yield of groundwater supply systems
Change in water quality	Yield of abstraction systems
Rise in sea level	Saline intrusion into coastal aquifers Movement of salt-front up estuaries, affecting freshwater abstraction points
Change in evaporation	Yield of reservoir systems

Obviously, changes in river runoff will affect the yields of both direct river abstractions and reservoir-based supply systems, and changes in groundwater recharge will affect groundwater yield. Changes in water quality will affect the amount of suitable water available to a supply system. A rise in sea level has two potential effects. First, there is a risk of saline intrusion into coastal aquifers, contaminating the water supply. This is a major potential threat—particularly to small, low-lying islands, whose main source of water frequently is a shallow lens of freshwater lying just a few meters above sea level (see Chapter 9). Second, a rise in sea level would mean that saltwater could penetrate further upstream into an estuary, perhaps threatening low-lying freshwater intake works. The effects of these changes in the amount of water available on water uses—and hence on system risk and reliability—will be influenced by changes in demands.

Section 14.2.2 reviews some published studies on changes in resource availability at the catchment scale (which focus mostly on surface water resources), and Section 14.2.3 broadens the perspective to a regional scale. Section 14.2.4 reviews how changes in water quality affect the availability of water resources. The effects of changes in hydrological regimes and water quality are examined in Chapter 10.

14.2.2. The River Catchment Scale

This section looks at the availability of water supplies under changed climatic conditions. For hundreds of years, people have adapted their habits and economic activities to relatively variable climatic and hydrological conditions—implicitly assuming that the average climatic state and the range of variability are stable.

This assumption may no longer be valid in some regions of the world because of possible alterations in stochastic properties of hydrological time series. Differences in the output of GCMs coupled with the variety of hydrological transfer models make it difficult to offer a reliable region-specific assessment of future water availability. It is doubtful whether the current technique of conducting "worst-case" analyses—wherein the most extreme scenario of a given GCM is used to develop hydrological responses—is useful for a critical appraisal of regional sensitivities to climate change. If anything, this type of analysis skews the evaluation and deflects the search for pragmatic responses. Progress in hydrological sensitivity analyses in developed nations is accompanied by large information gaps for developing countries that are most often affected by aridity and desertification. Although numerous new water resources impact studies have been conducted, few are from Africa, Asia, South America, or developing countries in general.

Studies that have considered possible changes in water supply in specific areas fall into three groups. The first group of studies infers changes in potential supply directly from modeled changes in annual and monthly water balance. Problems in maintaining summer supplies from direct river abstractions may be inferred, for example, if summer river flows are projected to decline (Arnell and Reynard, 1993). The second group of research has considered the sensitivity of hypothetical supply systems—usually single reservoirs—to changes in inputs. The third group of studies has largely been conducted since IPCC's 1992 Supplementary Report and consists of investigations into specific water-supply systems. Some have looked at individual reservoirs or groundwater resource systems; others have examined entire integrated water-supply systems, including real system operating rules. Table 14-2 lists these studies; several are summarized below.

These studies have simulated river flows using conceptual hydrological models but have used a variety of different scenarios. Mimikou *et al.* (1991), Wolock *et al.* (1993), Nash and Gleick (1993), and Kirshen and Fennessey (1995) all examine the effects of arbitrary changes in precipitation and temperature inputs to investigate the sensitivity of their modeled water resources systems to changes in inputs. A 20% reduction in rainfall in the Acheloos basin in Greece, for example, would increase the risk of system failure (inability to provide target supplies) from less than 1% to 38% (Mimikou *et al.*, 1991); similarly, with a 20% reduction in rainfall, the New York City reservoir system in the upper Delaware valley would be in a "state of crisis" between 27% and 42% of the time, depending on temperature increases (Wolock *et al.*, 1993). Nash and Gleick (1993) and Kirshen and Fennessey (1995) additionally use scenarios based on equilibrium GCM experiments, as do Gellens (1995), Kaczmarek and Kindler (1995), Riebsame *et al.* (1995), Salewicz (1995), Strzepek *et al.* (1995), and, in a generalized way, Hewett *et al.* (1993). All of these studies indicate that water resources systems could be very vulnerable to change in climatic inputs and that a small change in inputs could lead to large changes in system performance, but that there is considerable variability between scenarios. Riebsame *et al.* (1995) found isolated single-reservoir systems in arid and semi-arid regions to be extremely sensitive and less able to adapt (greater than 50% decreases in reservoir yields), with economic and ecological crisis conditions developing in some basins under climate change and seasonal flooding problems in others.

The remaining set of studies (Hobbs *et al.*, 1995; Lettenmaier *et al.*, 1995a, 1995b, 1995c, 1995d, 1995e; Steiner *et al.*, 1995; Waterstone and Duckstein, 1995; Shiklomanov *et al.*, 1995), largely undertaken in the United States, have used scenarios based on the three most recent transient GCM simulations (GFDL-tr, UKMO-tr, and MPI-tr) to investigate possible impacts on integrated, multipurpose water resources systems. All of these studies note the difficulties in forecasting meaningful impacts under the wide range of uncertainties inherent in the analysis; in many cases, the GCM simulations did not reproduce current catchment climate very well. However, a general conclusion from the studies is that even with the large variability in future climate represented by the three transient GCM experiments, most of the systems investigated possess the robustness and resilience to withstand those changes, and adequate institutional capacity exists to adapt to changes in growth, demands, and climate. This conclusion is in contrast to that of many other studies—some summarized above—that have found large changes in system reliability under climate change. There are two main reasons for this difference: First,

Table 14-2: Investigations into effects of global warming on specific water resources systems.

Location	Reference
Africa: Nile River	Strzepek *et al.* (1995)
Africa: Zambezi	Riebsame *et al.*(1995)
Africa: Zambezi River	Salewicz (1995)
Asia: Ganges and Brahmaputra	Kwadijk *et al.* (1995)
Asia: Indus River	Riebsame *et al.* (1995)
Asia: Mekong River	Riebsame *et al.* (1995)
Belgium	Gellens (1995)
England (southeast)	Hewett *et al.* (1993)
Greece	Mimikou *et al.* (1991)
Poland	Kaczmarek and Kindler (1995)
Russia and Ukraine: Dnipro River	Shiklomanov *et al.* (1995)
Uruguay	Riebsame *et al.* (1995)
USA: Boston area (1)	Kirshen and Fennessey (1995)
USA: Boston area (2)	Lettenmaier *et al.* (1995b)
USA: Colorado River	Nash and Gleick (1993)
USA: Columbia River	Lettenmaier *et al.* (1995c)
USA: Delaware River	Wolock *et al.* (1993)
USA: Great Lakes	Hobbs *et al.* (1995)
USA: Missouri River	Lettenmaier *et al.* (1995d)
USA: Potomac River	Steiner *et al.* (1995)
USA: Rio Grande River	Waterstone and Duckstein (1995)
USA: Savannah River	Lettenmaier *et al.* (1995a)
USA: Tacoma area	Lettenmaier *et al.* (1995c)

the transient scenarios tend to produce smaller changes in climate than the scenarios based on earlier GCMs; second, the transient-GCM studies examine highly integrated systems, which are inherently more robust than the isolated single-reservoir systems investigated in most other studies.

In some countries, water is predominantly taken from rivers, lakes, and reservoirs; in others, it largely comes from aquifers: Only 15% of Norwegian water is taken from aquifers, for example, whereas 94% of Portuguese supplies comes from groundwater. There have been very few studies of changes in groundwater recharge and implications for aquifer yield. Hewett *et al.* (1993) simulate an increase in recharge, and hence an increase in reliable yield, in part of the chalk limestone aquifer in southern England, but different scenarios in the same region suggest a decline in yield. The effect of a sea-level rise on saline intrusion into coastal aquifers has been investigated in a number of small islands and has been found to be potentially significant (see Chapter 9). Studies in Britain, however, have found that although there are many coastal aquifers potentially at risk, a rise in sea level would have little effect on intrusion and yields (Clark *et al.*, 1992). Saline intrusion along estuaries generally has been found to pose limited threats to freshwater intakes because the change in the position of the salt front is small relative to the intertidal range (Wolock *et al.*, 1993; Dearnaley and Waller, 1993).

This section has introduced some of the studies into water resource availability that have been undertaken in the last five years. There are several points to draw in conclusion. First, there are considerable uncertainties in estimating impacts, due partly to uncertainties in climate-change scenarios and partly to difficulties in estimating the effects of adaptations—both autonomous and climate-induced—over the next few decades. Second, there is evidence that isolated, single-source systems are more sensitive to change than integrated, multipurpose systems, which are considerably more robust. Much of the world's water, however, is managed through single-source, single-purpose systems. Third, there is a suggestion that, in countries with well-managed, integrated water resources, the additional pressures introduced by climate change could be met, with some costs, by techniques already in place to cope with changing demands and management objectives. There is little information, however, about the economic and societal costs of this adaptation. Waterstone *et al.* (1995), for example, conclude that institutional adaptation—changes in water laws, organizations, prices, fees, water marketing, and reservoir operating criteria—could serve to ameliorate the combined effects of increasing population and warming in the semi-arid Rio Grande basin in the southwestern United States and Hobbs *et al.* (1995) believe that conventional management practices for coping with fluctuating lake levels would be capable of mitigating the effects of climate change on the Great Lakes. Fourth, and perhaps most important, some studies (Riebsame *et al.*, 1995; Strzepek *et al.*, 1995) show that water resources in developing countries often are small-scale, isolated, and under considerable stress and may have a difficult time adapting to climate change effectively. Although the latter studies cover a range of hydroclimatic zones, there is still a major gap in our understanding of the impacts of climate change on the less-developed world—a situation that urgently needs to be rectified. The U.S. Country Studies Program currently is cooperatively studying the vulnerability and adaptability of water resources systems in more than 30 developing countries, with results expected in 1996.

14.2.3. The Global and Regional Context

The growing interest in possible consequences of anthropogenic climate change on regional water resources has given rise to a wealth of studies on the sensitivity of water balance to climatic variables. Much less information is available on the economic and societal consequences of projected global warming. The heaviest current pressures on water resources are the increasing population in some parts of the world and increasing concentrations in urban areas. The illusion of abundance of water on the Earth has clouded the reality that in many countries renewable freshwater is an increasingly scarce commodity (Postel, 1992; World Bank, 1992, 1994; Engelman and LeRoy, 1993). Climate change is likely to have the greatest impact in countries with a high ratio of relative use to available renewable supply. Regions with abundant water supplies are unlikely to be significantly affected, except for the possibility of increased flooding. Paradoxically, countries that currently have little water—for example, those that rely on desalination—may be relatively unaffected.

One study (Strzepek *et al.*, 1995) suggests that, although global water conditions may worsen by 2025 due to population pressure, climate change could have a net positive impact on global water resources. This result, presented in Figure 14-1, is based on runoff characteristics obtained for one particular climate scenario (Miller and Russel, 1992) and should be interpreted with caution. Another macroscale study (Kaczmarek *et al.*, 1995)—based on three transient climate scenarios—leads to a similar conclusion for the Asian continent, while suggesting that in Europe changed climatic conditions will be associated with some decrease of per capita water availability.

Following the concept of Falkenmark and Widstrand (1992) of a water stress index based on an approximate minimum level of water required per capita, Engelman and LeRoy (1993) use 1,000 m^3 per person per year as a benchmark for water scarcity around the world. They found that in 1990 about 20 countries, with a total population of 335 million, experienced serious chronic water problems and that by 2025, 31 countries with 900 million inhabitants could fall into this category because of expected population growth. Table 14-3 summarizes the combined impact of population growth and climate change on water availability in selected countries, based on the IPCC (1992a) socioeconomic scenarios and the results of three transient GCM runs. The second column lists per capita water availability for the present (1990); the third column shows water availability for current climatic conditions, reflecting population growth alone to the year 2050. The last column shows the range of

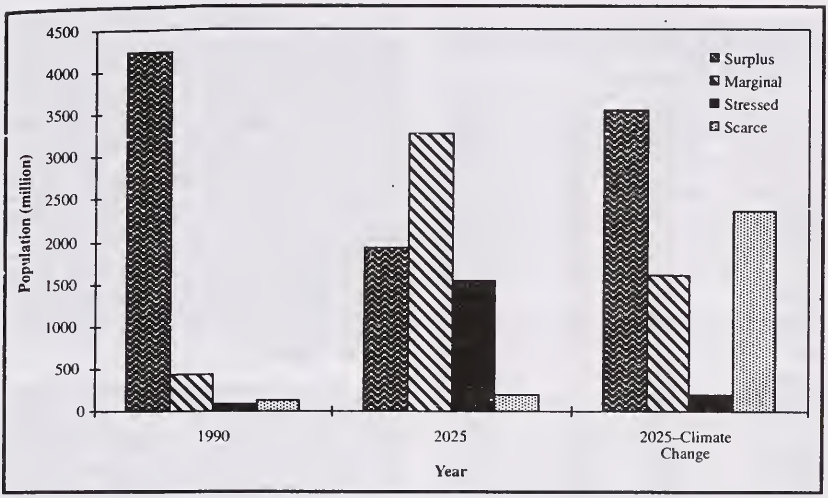

Figure 14-1: Global freshwater vulnerability (Strzepek *et al.*, 1995).

combined effects of population growth and climate change for the three transient scenarios. The sensitivities of national water supplies to changes in temperature and precipitation were estimated by a method proposed by Kaczmarek (1990). It should be added that the future water availability data do not take into account possible changes in water resources systems development (e.g., increased storage, desalination).

The results show that in all countries with high population-growth rates, future per capita water availability will decrease independent of the assumed climate scenario. Large discrepancies may be noted among results obtained for some countries by means of various atmospheric models. This example clearly demonstrates how difficult it would be to initiate water resources adaptation actions based on currently available methods of climate predictions. It can be expected that in many regions of the world, nonclimatic factors will dictate what measures must be undertaken to secure sustainable water supply (Frederick, 1994; Rogers and Lydon, 1994). Predicted climate changes, however, could redistribute water supplies, adding a new, highly uncertain component to the challenge of managing water resources.

Although it is appealing to devise thresholds or benchmarks for water scarcity, such as the one proposed by Falkenmark and Widstrand (1992)—in which economic water scarcity is defined as the condition in which renewable freshwater availability falls below 1,000 m³ per person per year—it is important to realize that such a threshold is useful only as a rough benchmark for comparison of relative conditions, perhaps to serve as a cautionary flag. Other comparable thresholds have been suggested at 1,700 m³ per person per year to reflect a condition of water stress, whereas the World Bank (Falkenburg *et al.*, 1990) suggests a 500 m³ per person per year threshold. On the other hand, Rogers (1992) considers such thresholds not useful in developing water management strategies, noting that both Malta and Israel—with annual per capita water availabilities of 85 m³ and 460 m³, respectively—are doing quite well in managing, recycling, and reclaiming their very limited water supplies.

Water availability, food production, population and economic growth, and climate change are linked in a complex way. Conflicts among interests are inherent in regional water management, particularly in regions with scarce water resources. Four objectives important for sustainable water planning may be identified: economic efficiency, environmental quality, equity considerations, and reliability. Transformation in the structure and characteristics of water supply and demand due to climatic and nonclimatic factors may add new aspects to existing social and political problems. Socioeconomic factors greatly influence the ability to solve these problems in the absence of necessary institutions, capital, and technology.

Access to freshwater may be complicated by conflicts arising over rights to water in shared river basins (e.g., Mekong and Nile—Riebsame *et al.*, 1995) and in aquifers that cross international borders (Engelman and LeRoy, 1993). A great number

Table 14-3: Water availability (m³/yr) in 2050 for the present climatic conditions and for three transient climate scenarios (GFDL, UKMO, MPI).

Country	Present Climate (1990)	Present Climate (2050)	Scenario Range (2050)
China	2,500	1,630	1,550–1,780
Cyprus	1,280	820	620–850
France	4,110	3,620	2,510–2,970
Haiti	1,700	650	280–840
India	1,930	1,050	1,060–1,420
Japan	3,210	3,060	2,940–3,470
Kenya	640	170	210–250
Madagascar	3,330	710	480–730
Mexico	4,270	2,100	1,740–2,010
Peru	1,860	880	690–1,020
Poland	1,470	1,250	980–1,860
Saudi Arabia	310	80	30–140
South Africa	1,320	540	150–500
Spain	3,310	3,090	1,820–2,200
Sri Lanka	2,500	1,520	1,440–4,900
Thailand	3,380	2,220	590–3,070
Togo	3,400	900	550–880
Turkey	3,070	1,240	700–1,910
Ukraine	4,050	3,480	2,830–3,990
United Kingdom	2,650	2,430	2,190–2,520
Vietnam	6,880	2,970	2,680–3,140

of water resources systems are shared by two or more nations. In several cases, there have already been international conflicts. As a result of population pressure, and in cases of negative impacts of climate change, tensions are likely to increase. In order to avoid future conflicts over water use among riparian countries, joint legal agreements should be established. One possibility is to form international water agencies or commissions, with terms of reference including inventory, assessment, monitoring, and apportionment of water resources and due account for possible changes caused by climatic trends. Joint planning is essential for basin-scale water resources development and management in order to cope with negative consequences of climate change. International water agencies should arbitrate on regional water issues and be supported by national legal frameworks to back the regional arbitration accordingly. To be able to fulfill this task, international water agencies in developing countries require well-trained people with knowledge of global-scale processes and, in some cases, external funding for research and development.

14.2.4. Implications of Changes in Water Quality

Water management is concerned not merely with the supply of water but with the supply of water of appropriate quality as well. The definition of "appropriate" varies among uses. Potable water has to be of the highest quality, whereas industry and, to a lesser extent, agriculture can use lower-quality water. Irrigation increasingly employs recycled "dirty" water, raising concern about salinity and public acceptance of wastewater use. Many water management problems around the world today, in fact, relate to the quality of surface water and groundwater. Climate change might exacerbate some of these problems by complicating an already expensive, evolving management process. Water-quality problems usually stem from some form of pollution, ranging from the discharge of untreated sewage into watercourses to the discharge of treated sewage effluent, the leaching of agricultural chemicals, and chemical and thermal pollution from industry. There is a considerable range of experience in dealing with water quality. In some countries, the focus is on preventing poor water quality; in others, effort is directed toward rehabilitation, treatment, sanitation, and public health. In many countries, water quality is hardly addressed at all.

The potential effects of climate change on aquatic ecosystems are reviewed in Chapter 10. Of particular concern for water users are dissolved oxygen content, nitrate and organic pollution concentrations, sediment load, and salinity. The main conclusion is that rivers that presently have poor water quality are likely to be those most affected by changes in temperature, lower flow rates, and increased input of pollutants; climate change is therefore likely to exacerbate water-quality problems in places where such problems already are potentially severe.

Water management agencies in many countries are spending significant sums on maintaining and improving surface and groundwater quality. Although approaches vary, improvement plans tend to include target water-quality and effluent standards, infrastructure for treating effluent returns and polluted water, policies to prevent pollution, and policing. These actions also can be used to maintain and improve water quality under climate change, obviously at some additional cost. For example, it may be necessary to reduce the quantity of treated effluent that can be discharged to a stream with reduced flows, with consequent implications for the discharging organization.

14.3. Impact of Climate on Water Demands

Section 14.2 considered changes in the ability of water resources systems to supply water; this section looks at the demand side. It is useful to distinguish between offstream demands—specifically domestic, industrial, and agricultural demands—and instream demands, such as power generation, navigation, recreation, and ecosystems protection. Increases in water demand are driven by population and economic growth. Demand management has two dimensions: the first long-term, the second in response to short-term shortages. In the long term, one can reduce offstream water demands substantially through technological, economic, legal and administrative, and educational measures. In the short term, demand during temporary supply shortages can be managed through demand reduction measures (such as rationing) and public education.

14.3.1. Agricultural Water Demands

At present, more than 65% of global water withdrawals is for agricultural use; much of this is evaporated and consequently lost to catchment runoff. Irrigation increased significantly until the 1970s, when the rate of expansion fell sharply; since 1980, the annual rate of expansion has been less than 1%—less than the rate of population increase (Postel, 1992). Rapid expansion in the future is unlikely as the cost of developing new schemes increases and investments in irrigation decline. Agricultural irrigation practices are inefficient in many areas of the world. Changes in irrigation technology (such as the use of drop irrigation) often can compensate for anticipated increases in food demands. The effects of climate change on agricultural policy and irrigation requirements are discussed in Chapter 13. It is important to emphasize that the effects of climate change on agricultural demands for water, particularly for irrigation, will depend significantly on changes in agricultural potential, prices of agricultural produce, and water costs.

Both rainfed and irrigated crops will require more water in a warmer world, and this water may not be available through increased precipitation. Allen *et al.* (1991) simulate changes in irrigation demand in the Great Plains region of the United States, showing that the demand for water to irrigate alfalfa would increase, due largely to increases in the length of the crop growing season and crop-water requirements during summer. Another U.S. study—based on a Thornthwaite water-balance model (McCabe and Wolock, 1992)—indicates that, for a broad range of increases in temperature and precipitation, annual irrigation demand increases, even with a 20% increase in precipitation. In a study in Lesotho, Arnell and Piper (1995) simulate an increase in irrigation demands of 7% with a 10% decline in runoff and an increase of more than 20% with a 2°C increase in temperature. They also examine the performance of a hypothetical reservoir supplying irrigation water and find major changes in the reliability of supply. Studies in the UK lead to the conclusion that an increase in temperature of 1.1°C by 2050 may result in an increase in spray irrigation demands of 28%, over and above a projected 75% increase to meet growing demands (Herrington, 1995). Similar calculations in Poland result in a 12% increase in irrigation demands with a 1°C temperature increase and a 1.8% change in water requirements with a 1% precipitation change during the vegetation season. Irrigation demand seems to be more sensitive to changes in temperature than to changes in precipitation. Model results indicate that increased stomatal resistance to transpiration counteracts the effects of temperature increases on irrigation demand.

14.3.2. Municipal Demands

Municipal demands are essentially for domestic and commercial uses. In many developed countries, some components of demand are decreasing due to greater appliance efficiency, but others are increasing as new appliances, such as waste disposal units and automatic washing machines, become more widespread. Herrington (1995) estimates changes in the components of domestic demand in southern England, with and without climatic change and assuming no change in water pricing policies. An increase in per capita demand of 21% is projected between 1991 and 2021 without climate change, with an additional 5% increase due to global warming—largely due to an increase in garden water use. Other studies have found a similar percentage change in domestic and municipal demand due to global warming (Cohen, 1987; Kaczmarek and Kindler, 1989; Kirshen and Fennessey, 1993; Hanaki, 1993; Steiner *et al.*, 1995). Little is known about the impact of climate change on domestic water use in developing countries, but nonclimatic factors—population growth, economic development, water-use efficiency, and water pricing—probably will dominate in shaping trends of future water use in most African and Asian regions.

14.3.3. Industrial Water Use and Thermal and Hydropower Generation

In most developed countries, the demand for water for industrial purposes is declining as traditional major water users such as the steel industry decline in significance and as water is used more efficiently. It should be added, however, that in many cases these water-consuming industrial users are relocating to the developing world, complicating the water resource situation in those regions. Strzepek and Bowling (1995) have found that under a moderate growth assumption, global industrial water use in 2025 may increase by 1.7 to 2.3 times 1990 levels, and most of this growth will occur in the developing world. Climate change is expected to have little direct impact on industrial water use.

A change in water quantity may affect the degree to which demands for cooling water can be satisfied, and a rise in water temperature will reduce the efficiency of cooling systems (Dobrowolski *et al.*, 1995). It also might be more difficult to meet regulatory constraints defining acceptable downstream water temperatures, particularly during extreme warm periods. Several French nuclear power stations were forced to close down or operate well below design capacity during the drought of 1991. A reduction in water availability might lead to an increase in the use of closed-cycle cooling systems as simulated in the Tennessee Valley Authority system (Miller *et al.*, 1993). Changes in water availability and temperature may not cause significant impacts on long-term or annual total production potential—only a 2% decline in annual net system generation was found in the Tennessee Valley—but they could cause short-term operational problems during critical periods.

A change in hydrological regimes has an obvious potential impact on hydropower production but also may affect thermal power generation and general industrial demands for cooling water. Mimikou *et al.* (1991) show a very large change in the risk of being unable to generate design power from hydropower reservoirs in central Greece. In Norway, Saelthun *et al.* (1990) find increased generation potential due largely to a shift in the timing of inflows, mainly as a result of reduced snowfall; the current "waste" of power in the spring is much reduced.

Riebsame *et al.* (1995) examine hydropower generation in four developing-country basins. In the Zambezi basin, the possible reduction of hydropower at Lake Kariba could be replaced by the construction of a new plant at Batoka Gorge, but for a significant cost. Hanemann and McCann (1993) examine the economic cost of changes in hydropower potential in northern California. Under a scenario based on the GFDL equilibrium GCM, annual hydropower production would decrease by 3.8%; production would be 48% higher in January but as much as 20% lower during the peak-load summer months. Water would have to be released during the spring to leave room for flood control. As a result of the reduced hydropower generation, production of power by natural gas would have to increase by 11% to meet the same demands, leading to a $145 million (1993 prices) increase in annual system costs (12.5%). In some cases, the expected shift in the runoff hydrograph, combined with changes in the distribution of irrigation water demands, may lead to reduced energy generation.

14.3.4. Navigation

Changes in flow regimes and lake levels can be expected to affect navigation potential, but there have been very few studies on this topic. The sensitivity of river navigation to extreme conditions was well illustrated on the Mississippi River during the drought of 1988, when river traffic was severely restricted (with consequent effects on the agricultural sector due to difficulties in transporting the grain harvest). High river flows also restrict navigation by increasing energy costs and flooding riverside facilities. Navigation on the river Rhein, for example, is constrained by periods of both high and low flows, and considerable sums are spent on dredging and maintaining channels; a change in sediment load could have major implications for these activities. An increase in temperature, however, would increase the duration of the navigation season on rivers affected by seasonal ice cover. Studies in the Great Lakes (Chao *et al.*, 1994) suggest that a longer shipping season due to a reduction in ice cover would just compensate for lost draft due to lower levels; shipping companies would be able to adjust their operating season in the Great Lakes because many of the raw materials transported are stockpiled.

14.3.5. Recreation and Other Instream Water Uses

There have been very large investments in water-based recreation in many countries, and many large facilities are operated to maximize recreation potential. The effects of global warming on recreation are difficult to determine. Changes in the volume of water stored in a reservoir might affect the use of the reservoir for recreation (Frederick, 1993), and a change in water quality might also affect the recreational use of the water. There are established procedures for estimating the economic benefits of access to recreation, but the sensitivity of recreational use to hydrological characteristics—reservoir storage volume, water quality, and so forth—is not well known; the effects of possible changes therefore are difficult to quantify. One exception is the Great Lakes, where there are clear relationships between beach area, length of recreation season, and recreational benefits: Both beach area and recreation season length would increase under climate warming, resulting in an estimated doubling of recreational benefits, according to Chao *et al.* (1994).

One-tenth of the world's commercial fish yield is obtained from inland waters (Covich, 1993), and recreational fishing also has high economic value. The effects of changes in water temperature, water quality, and river flow regimes on fish populations are outlined in Chapter 10; this section focuses on implications of changes for sport fishing and aquaculture. Hanemann and Dumas (1993) simulate the effects of one global warming scenario on Chinook salmon runs in the Sacramento River, California, and find a reduction in the salmon population largely due to reductions in spawning habitats. Loomis and Ise (1993) estimate the change in the economic value of recreational fishing in the Sacramento River based on an empirical relationship between the number of fish caught and the number of fishing trips made. The reductions in fish population result in an annual loss of recreational benefit of $35 million (1993 values)—a 23% decrease (assuming no change in anglers' willingness to travel to the river).

Stefan *et al.* (1993) conclude that, for the state of Minnesota, the impact of climate change on fishery resources may be significant. Overall fish production may increase, but cold-water fisheries will be replaced in part by warm-water fisheries. This coincides with findings in Poland and Hungary related to the impact of thermal pollution. The comprehensive study of fish yields performed by Minns and Moore (1992) in several hundred watersheds in eastern Canada shows considerable redistribution of fishery capability.

The final instream use to be considered in this section is ecosystem protection. Instream ecosystems demand a certain minimum quantity of water (which may vary throughout the year), and water managers in many countries increasingly are balancing these demands with those of more traditional water users. Several techniques are being developed to estimate instream demands (Stalnaker, 1993); these techniques can be used in principle to estimate the effects on these demands of changes in water availability. However, this has not yet been done, largely because the instream demand models are very uncertain. In principle, it might be possible to maintain certain aquatic ecosystems by managing river flow regimes to minimize changes, but this is perhaps not desirable in an ecological sense because it would create a system that would not be sustainable without human intervention. The general issue of managing the impacts of climate change on natural ecosystems is discussed in Chapter 10 and elsewhere.

14.3.6. Competition Between Demands

Water demand in general increases in all sectors with an increase in temperature; this is a well-accepted consequence of climate change. At the same time, regional and local precipitation changes, which will have important impacts on water demands, are much less clear. Studies of individual sectors and systems show great potential for adapting to water conditions in a changed climate. However, as we move into the 21st century, population and economic pressures may create water-stressed conditions in many parts of the world. Many of the responses being proposed to adapt to climate change require reduction of demands and reallocation of water among water-use sectors.

Present water management is concerned with reconciling competing demands for limited water resources. Currently, these conflicts are solved through legislation, prices, customs, or a system of priority water rights. Change in the amount of water available and water demands is likely to lead in many cases to increased competition for resources. Conflicts may arise between users, regions, and countries, and the resolution of such conflicts will depend on political and institutional arrangements in force. The challenge will be to create integrated demand/supply management systems, as discussed below.

14.4. Management Implications and Adaptation Options

14.4.1. Considerations for Response Strategies

In general, most countries and civilizations have faced water shortages due to natural climate variability, anthropogenic changes and desertification, or overexploitation and pollution of the resource base. Management of water resources inherently entails mitigating the effects of hydrological extremes and providing a greater degree of reliability in the delivery of water-related services. Because different uses have different priorities and risk tolerances, the balance points among them after climate change could be quite different from the present (e.g., hydropower and instream uses may be lost disproportionately compared to water supply). No enterprise is risk-free: Society decides on the level of risk-bearing through the acceptance of certain levels of risk and reliability, as expressed by cost-effective standards and criteria. The marginal cost of reducing each additional increment of risk typically rises rapidly as reliability approaches 100%. Hence, water managers usually deal with 90%, 95%, and 99% levels of reliability as useful performance measures of the available quality and quantity of water.

The same is true in mitigating other natural hazards, especially in traditional approaches to drought mitigation, flood control, and damage mitigation. Given some of the preliminary results of GCM experiments regarding potential changes in rainfall intensity and frequency (Gordon *et al.*, 1992; Whetton *et al.*, 1993), it appears that flood-related consequences of climate change may be as serious and widely distributed as the adverse impacts of droughts. This should raise concerns about dam safety and levee design criteria and spur reconsideration of flood plain management policies. The devastating floods of 1993 in the upper Mississippi River basin have resulted in a U.S. Interagency Floodplain Management Review Committee report (1994) on just such policy issues, exemplifying the need for constant adaptation in the field of water resources management. Comparable adaptations are anticipated in the wake of the most recent European floods of January 1995.

To alleviate human-induced droughts occurring at a regional scale as a consequence of inappropriate land-use practices, wise criteria for land use should be developed to minimize storm-induced runoff and, consequently, minimize erosion and nutrient loss and maximize interception and infiltration. Such strategies would maintain or enhance the recycling of moisture, which at a (sub)continental scale is necessary to sustain rainfall in the region. Most watershed management practices for erosion control and water harvesting do contribute, albeit unintentionally, to the reestablishment of moisture feedback to the atmosphere and, consequently, to the recycling of moisture and rainfall. In view of the vulnerability of regions presently affected by anthropogenic droughts and the dire consequences of resulting desertification, this field of research merits full attention.

The first IPCC reports (1990a, 1990b) contain a discussion of the philosophy of adaptation and a list of adaptation options suited to the range of water management problems that are expected under climate change. Based on a review of the most recent literature, no additional water management actions or strategies unique to climate change have been proposed as additions to the list, other than to note that many nations have pledged to implement action plans for sustainable water resources management as part of their obligation toward Agenda 21. In that respect, the principles laid out in that document would serve as a useful guide for developing a strategy that would enable nations, river basin authorities, and water utilities to prepare for and partially accommodate the uncertain hydrologic effects that might accompany global warming. The World Bank (1993) lays out a framework for water resources management that is expected to serve the needs of developing nations well into the next century and to meet the objectives of Agenda 21.

There are many possibilities for individual adaptation measures or actions. An overview of water supply and demand management options is presented by Frederick (1994) as part of an attempt to develop approaches for dealing with increasing water scarcity. A long-term strategy requires the formulation of a series of plausible development scenarios based on different combinations of population growth assumptions along with economic, social, and environmental objectives (Carter *et al.*, 1994). After these scenarios are established, taking into account the possibility of climate change, a set of alternative long-term strategies for water management must be formulated that consists of different combinations of water management measures, policy instruments, or institutional changes, and is designed to best meet the objectives of a particular growth and development scenario and its consequent CO_2 emissions rate. The range of response strategies must be compared and appraised, each with different levels of service reliability, costs, and environmental and socioeconomic impacts. Some will be better suited to dealing with climate change uncertainty (i.e., more robust and resilient), and others will focus on environmental sustainability. Some are likely to emphasize reliability of supply. The reality is that, after the application of engineering design criteria to various alternatives, the selection of an "optimal" path is a decision based on social preferences and political realities. Engineering design criteria, however, also evolve over time and are updated as new meteorological and hydrological records are extended and the performance of water management systems is tested under varying conditions.

All major institutions that deal with water resources planning and management agree that future water management strategies should include various cost-effective combinations of the following management measures:

- Direct measures to control water use and land use (regulatory, technological)
- Indirect measures that affect behavior (incentives, taxes)
- Institutional changes for improved management of resources
- Improvement in the operation of water management systems
- Direct measures that increase the availability of supply (reservoirs, pipelines)
- Measures that improve technology and the efficiency of water use.

Different strategies apply to different circumstances. Watersheds that have little or no control over natural flows and are largely dependent on precipitation must implement a different set of water management strategies than river basins with a high degree of control in the form of reservoirs, canals, levees, and so forth. Similarly, rapidly urbanizing areas will require different responses than agricultural regions. There is no standard prescribed approach. However, a rational management strategy undertaken to deal with the reasonably foreseeable needs of a region in the absence of climate change, according to the principles espoused in Agenda 21, also will serve to offset many of the possible adverse consequences of climate change.

14.4.2. Implications for Planning and Design

The nature of contemporary water resources management is such that countless numbers of principal factors, economic criteria, and design standards are incorporated simply because of the complexity of integrated water management (e.g., hydropower, ecosystem support, water supply) and objectives (e.g., reliability, costs, safety). Some factors that are routinely assessed inherently represent design thresholds such as the minimum instream flow required for maintaining an aquatic ecosystem or the "probable maximum flood" that is used for most dam-safety risk analyses. The accepted level of water supply reliability of a system is a threshold as well, determined essentially by public preference, economics, and engineering analysis. Planning, by its nature, has inherent risks and develops alternative plans that are packages of complementary actions, project regulations, and management measures that reduce risks in different water-use sectors (with a variety of socioeconomic and environmental impacts and a range of benefits and costs).

Engineering design is largely concerned with performance and reliability. Once a particular plan is selected, engineers ensure that each of the separate components functions as planned and that, collectively, the water management system performs reliably. This was true in Roman times (Frontinus, 98 AD) as well as in contemporary times. Water resources systems are designed to perform reliably over most but not all of the range of anticipated hydrological variability. That reliability criterion is determined through a combination of risk, costs, benefits, environmental impacts, and societal preference. Hence, if climate change alters the frequency, duration, and intensity of droughts and floods, new reliability criteria will evolve over time to adjust for the perceived changes in both availability and use—as will the corresponding types of adaptive behavior.

It also is useful to think of hydrological or watershed response sensitivity to change measured in terms of physical effects. A complementary notion is the susceptibility of various water-use sectors (e.g., hydropower, irrigation, recreation) to incremental changes of outputs (e.g., kilowatt-hours, revenues, visitors). Finally, the vulnerability to failure of a water management system itself—consisting of pipes, pumping stations, reservoirs, and delivery rates—also must be appraised in terms of reliability targets measured as changes in quality, quantity, and probability. To that end, water resources planners, hydrologists, and design engineers have developed a set of practices that explicitly address a range of hydrological, economic, and engineering risk and uncertainty factors and implicitly encompass some notion of sensitivities and thresholds. Fiering (1982) and Hashimoto *et al.* (1982a, 1982b) developed the concepts of robustness (sensitivity of design parameters and economic costs to variability); reliability (a measure of how often a system is likely to fail); resiliency (how quickly a system recovers from failure); vulnerability (the severity of the consequences of failure); and brittleness (the capacity of "optimal" solutions to accommodate an uncertain future). Many if not most of these concepts are analyzed as part of contemporary hydrological and water resources management decisions (Kundzewicz and Somlyody, 1993; Kaczmarek *et al.*, 1995). Riebsame *et al.* (1995) analyze the sensitivities and adaptabilities of five international river basins in the context of the criteria discussed above. The results are presented in Table 14-4.

Table 14-4: *Overall basin sensitivity and adaptability (Riebsame et al., 1995).*

Basin	Hydrological Sensitivity	Structural Robustness	Structural Resiliency	Adaptive Capacity
Uruguay	moderate	high	high	high
Mekong	low	low	high	low
Indus	moderate	high	moderate	high
Zambezi	high	low	low	low
Nile	high	high	low	low

There is a growing tendency to devise management systems that complement supply development with demand management. Nonstructural management measures are increasingly relied on to provide needed robustness without decreasing the overall reliability of a system. Hence, flood-control levees in the United States are now designed to provide varying levels of protection, whereas in the past there was a fixed level of flood protection based on a calculation of the "standard project flood." Today, a levee can be designed to offer protection against a flood with a 2% chance of occurrence (a 50-year return period) in conjunction with a well-organized flood warning and evacuation plan. For example, all 360 U.S. Corps of Engineers reservoirs have both drought contingency plans and flood warning and dam-safety evacuation plans. However, it is important to remember that the combination of numerous design factors, operating rules, reservoir storage allocation decisions, flood forecasting and evacuation planning, and drought contingency planning provides a considerable degree of robustness, resiliency, and flexibility to contend with uncertainty and surprises. Coupled with demand management and institutional and regulatory changes that are needed to cope with anticipated changes in population and demands, water management systems of this scale, if properly managed, offer a well-balanced strategy for dealing with risk and uncertainty, including many of the impacts of climate change. The purpose is to reduce, if not minimize, the adverse social, economic, and environmental consequences of changes in water resources regardless of the agent of change (Stakhiv, 1994), although the costs of adaptation to climate change could be substantial. Most important is the reality that water resources management is an inherently continuous adaptive endeavor at many different levels and spatial scales.

This is not to suggest that we can become complacent in our response to climate change. The challenges and barriers to implementing the water management principles of Agenda 21 are difficult enough to overcome. The water situation in the Middle East and North Africa is precarious and projected to deteriorate as a consequence of population growth and unplanned development. In sub-Saharan Africa (World Bank, 1994), the water situation is expected to worsen due to desert encroachment and drying up of water sources as a result of increased deforestation. Droughts, desertification, and water shortages are a permanent feature of daily life in those countries. The list of nations with water supply problems will expand with the accelerated pace of urbanization. By the year 2030, urban populations will be twice the size of rural populations. By 2000, there will be 21 cities in the world with more than 10 million inhabitants, 17 of which will be in developing countries. It is expected that the population without safe drinking water will increase from 1 billion people in 1990 to 2.4 billion by 2030, assuming a "business-as-usual" scenario. Similarly, population without adequate sanitation will grow from 1.7 billion to 3.2 billion by the year 2030 (World Bank, 1992). Addressing these issues would make it easier to cope with the impacts of climate change when and if they become significant (IPCC, 1992; Goklany, 1992).

On the other hand, the picture may not be as bleak as it appears, in the sense that it is easier and more efficient to organize a water supply, treatment, and delivery system for urban areas with concentrated populations. Also, demands can be more easily managed to promote water-use efficiency. Although municipal and industrial water use will grow, per capita use is likely to decrease and the quality of drinking water will increase with centralized treatment. Many future urban water demands are likely to compete with the irrigated agricultural sector—which uses about 88% of all water withdrawn in Africa, 86% of all water withdrawn in Asia, and 87% of all water withdrawn in the arid Middle East and North Africa (World Bank, 1994). New sources of supply will have to be developed, but existing water use will have to be more effectively managed and efficiently used.

The reality is that increasing water demands will intensify competition for scarce water and further concentrate water use in urban centers. During the next 30 years, these real and complex needs will preoccupy water managers. Water management planning will address these needs, which precede the climate-change signal and thereby serve as a *de facto* adaptation mechanism. Climate change, in its many manifestations, is likely to be a perturbation on what are already difficult and complicated water management problems. Existing drainage systems, water-control structures, and conveyance and distribution systems typically are designed on the basis of design floods or droughts of different return periods and/or annual exceedance probabilities, which are derived from past failures and associated perceived degrees of tolerable risk and economic costs. Because there is a significant turnover in water management infrastructure, with considerable maintenance and major rehabilitation occurring in most countries about every 30 years, it can be expected that the operating capacity of such structures can be made to conform to evolving changes in climate. Analytical tools are available to provide the necessary degree of confidence in the design and operation of such systems in a reliable manner.

14.4.3. Impact on Flood Risk and Management

Although the potential impact of global warming on the occurrence of flood disasters has been alluded to frequently in popular accounts of global warming, there have been very few studies addressing the issue explicitly. This is largely because it is difficult to define credible scenarios for changes in flood-producing climatic events (Beran and Arnell, 1995). Chapter 10 outlines the potential effects of global warming on riverine floods, and Chapter 9 reviews the effects of a rise in sea level and changes in storms on coastal flooding. This section considers the implications of changes in flood occurrence for flood risk and management. There are four major implications: a change in flood loss, a change in flood risk and the standard of service currently provided by flood management and protection schemes, a change in the cost of protecting against floods, and impacts on public and private financial institutions.

The effect of a change in the frequency of floods on flood losses has to be set against many other factors, including population growth, economic development, and expansion onto flood plains. These factors have large impacts, making it difficult to detect climate-related change on flood loss statistics.

It might be easier, however, to detect a change in the standard of service provided by existing flood management schemes. Flood protection works and flood plain land-use plans usually are based on either a risk analysis to determine the most cost-effective level of protection (balancing costs against benefits) or on some legislative or institutional guideline for standard of service. Urban-flood-protection works, for example, typically provide protection against floods with a return period of up to 100 years. A change in flood frequency characteristics can have a very significant effect on flood risk and hence standards of service: A small change in flood magnitudes can have a very large effect on the risk of a particular critical value being exceeded. Beran and Arnell (1995) have shown that, assuming statistical properties similar to those of British rivers, a 10% increase in the mean—with no change in the year-to-year variability of floods—would result in a current 10-year flood occurring on average once every 7 years.

Increased flood frequencies probably would lead to increased expenditures on flood management. Most directly, the costs of providing or improving structural flood defenses would increase; indirect costs to society also may be incurred if larger areas of potentially productive floodplain land are excluded from development by flood plain zoning policies. However, there have been no quantitative studies of the costs of maintaining flood protection in the face of global warming.

Finally, an increase in flood losses may place significant strains on public finances, if damages are covered by public funds, or on the insurance industry. The amount of aid provided varies from country to country, as does the amount of coverage provided by the insurance industry. At the global scale, the international insurance and reinsurance industry may be seriously threatened by the occurrence of a few large, closely spaced storm events.

The Mississippi floods of 1993 and the European floods of 1994/1995 triggered major reviews of flood management policies. It is unlikely that flood management in the 21st century will be similar to flood management in the 20th century; there will probably be an increasing emphasis on adopting nonstructural measures and coping with uncertainty in risk assessments. The future effects of global warming on flood risk and flood management therefore must be seen against this changing institutional and technical background.

14.5. Research Needs

Uncertainties and analytical difficulties confront attempts to quantitatively analyze the direct effects of global warming on water resources demands. Considerable research investment is required in order to improve prediction and adaptive responses in the face of these uncertainties and methodological problems, including:

- Uncertainties in GCMs and lack of regional specification of locations where consequences will occur
- The absence of information on future climate variability
- Uncertainties in estimating changes in basin water budgets due to changes in vegetation and atmospheric and other conditions likely to exist in the future
- Uncertainties in the future demands of each water sector
- Uncertainties in the socioeconomic and environmental impacts of response measures
- Water management criteria under a potential nonstationary climate
- Linkage of water and agricultural sectors through detailed study of the impact of climate change on irrigation
- The impact of land-use and land-cover changes on water management
- The role and impact on groundwater management and conjunctive use.

It is doubtful whether some of these uncertainties can be completely eliminated, and, as with anything in the future, unforeseen elements will arise.

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Climate Change 1995

Impacts, Adaptations and Mitigation of Climate Change:

Scientific-Technical Analyses

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Impacts on Forests

Q26. On pages 14 and 15 of your written testimony you also state the following:

"Forests: Climate change can dramatically alter the geographic distributions of individual tree species and of forest and vegetation types. One-third of the Earth's forests would undergo a major change in the type of vegetation that could be supported as a result of an equivalent doubling of CO2. In northern forests, which are the forests most vulnerable to climate change, two-thirds of the currently forested area may undergo a change in vegetation type. Mountaintop species and isolated populations are particularly vulnerable. Over the next century, the ideal range for some North American forest species will shift by as much as 300 miles to the north, exceeding the ability of many species to migrate. In some instances, a change in vegetation type will result in a loss of forest area as the land converts to grassland or shrub land, while in other areas forest cover may increase.

- **In the United States, western conifer forests could decrease in area and be replaced by broadleaf forests; eastern hardwood forests may be replaced by grasslands along their western boundary because of mid-continental drying. Forest damage from fire and diebacks driven by drought, insects and disease could increase."**

Please document these statements.

A26. Chapter 1 of the document *Climate Change 1995 – Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses* summarizes the IPCC's most recent conclusions on climate change impacts on forests. Forests are highly sensitive to climate change, which has been documented via past observations, experimental studies, and modeling. Sustained temperature increases of as little as 1°C can be sufficient to cause changes in the growth and regeneration capacity of many tree species. Suitable habitats are likely to shift faster than the maximum natural rate at which many species can migrate. A copy of this chapter of the document is attached.

1

Climate Change Impacts on Forests

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CONTENTS

EXECUTIVE SUMMARY

Forests are highly sensitive to climate change. This has been shown by observations from the past, experimental studies, and simulation models based on current ecophysiological and ecological understanding. In particular, the following was concluded:

- Sustained increases of as little as 1°C in mean annual air temperature can be sufficient to cause changes in the growth and regeneration capacity of many tree species. In several regions, this can significantly alter the function and composition of forests; in others, it can cause forest cover to disappear completely (Medium Confidence).
- Suitable habitats for many species or forest types are likely to shift faster with climate change than the maximum natural rate at which many species can migrate and establish. Consequently, slow-growing species, such as late successional species, or those with restricted seed dispersal will be replaced by faster-growing, highly adaptable or more mobile species (High Confidence).
- Forests are particularly vulnerable to extremes of water availability (either drought or waterlogging) and will decline rapidly if conditions move toward one of the extremes (High Confidence).
- Forced by a doubled carbon dioxide (2 x CO_2) climate, global models project that a substantial fraction of the existing forests will experience climatic conditions under which they do not currently exist; eventually, large forested areas will have to change from the current to new major vegetation types (High Confidence). Averaged over all zones, the models predict that 33% of the currently forested area could be affected by such changes; in the boreal zone, one model projects it to be as high as 65% (Medium Confidence). Yet it is currently not possible to predict transient forest responses at a regional to global scale.
- Although net primary productivity may increase, the standing biomass of forests may not increase because of more frequent outbreaks and extended ranges of pests and pathogens and increasing frequency and intensity of fires (Medium Confidence).
- Mature forests are a large store of terrestrial carbon. Because the maximum rate at which carbon can be lost is greater than the rate at which it can be gained, large amounts of carbon may be released transiently into the atmosphere as forests change in response to a changing climate and before new forests replace the former vegetation. The loss of aboveground carbon alone has been estimated to be 0.1–3.4 Gt yr^{-1} or a total of 10–240 Gt (Medium Confidence).

The following regional assessments were primarily based on transient climate-change scenarios for 2050 (Greco *et al.*, 1994).

Tropical Forests

- Tropical forests are likely to be more affected by changes in land use than by climate change as long as deforestation continues at its current high rate (High Confidence).
- Any degradation of tropical forests, whether it is caused by climate or land-use changes, will lead to an irreversible loss in biodiversity (High Confidence).
- CO_2 fertilization may have its greatest effect in the tropics and may lead to a gain in net carbon storage in undisturbed forests, especially in the absence of nutrient limitations (Medium Confidence).
- Tropical forests are likely to be more affected by changes in soil water availability (caused by the combined effects of changes in temperature and rainfall) than by changes in temperature *per se*. Decreases in soil moisture may accelerate forest loss in many areas where water availability is already marginal. In other areas, increasing precipitation may be more than adequate to meet increased evaporative demand and may even lead to erosion (Medium Confidence).

Temperate Forests

- Compared with other latitudinal zones, the potential area for temperate forests is projected to change the least; however, many existing forests will still undergo significant changes in their species composition (High Confidence).
- Water availability will change in many regions, and in some regions where water supply is already marginal, forests may be lost in response to increased summer droughts (Medium Confidence).
- While warming and elevated CO_2 are likely to increase net primary productivity of many forests, net carbon storage may not increase because of the associated stimulation of soil organic matter decomposition by soil warming (Medium Confidence).
- Temperate forests are currently a carbon sink, mainly because of regrowth that started in many regions in the 19th century. However, these forests could become a source if they degrade due to climate change or other causes such as air pollution (Medium Confidence).

- Most temperate forests are located in developed countries with resources to reduce the impacts of climate change on their forests through integrated fire, pest and disease management, and/or encouraging reforestation (Medium Confidence).

Boreal Forests

- Because warming is expected to be particularly large at high latitudes, and boreal forests are more strongly affected by temperature than forests in other latitudinal zones, climate change is likely to have its greatest impact on boreal forests (High Confidence).
- Northern treelines are likely to advance slowly into regions currently occupied by tundra. (High Confidence).
- Increased fire frequency and pest outbreaks are likely to decrease the average age, biomass, and carbon store, with greatest impact at the southern boundary where the boreal coniferous forest is likely to give way to temperate-zone pioneer species or grasslands (Medium Confidence).
- The net primary productivity of forests not limited by water availability is likely to increase in response to warming, partly mediated by increased nitrogen mineralization. However, there may be a net loss of carbon from the ecosystem because of associated increases in soil organic matter decomposition (Medium Confidence).

1.1. Introduction

Forests are among those ecosystems on Earth that remain the least disturbed by human influences. They are of great socioeconomic importance as a source of timber, pulpwood for paper making, fuel, and many non-wood products (see Chapter 15). Furthermore, forests provide the basis for a broad range of other economic and non-economic values, such as resources for tourism, habitat for wildlife, or the protection of water resources. Forests harbor the majority of the world's biodiversity (mainly in the tropics) and, as such, they represent indispensable, self-maintaining repositories of genetic resources. These are essential for improvements in crop and timber selection and in medicine. Finally, aside from special economic interests, forests are also of spiritual importance to many indigenous people.

Globally, forests in 1990 covered about one-fourth of the Earth's land surface (3.4 Gha: FAO, 1993b), although estimates differ due to the exact definition of forests (e.g., 4.1 Gha: Dixon *et al.*, 1994; or, in a very wide definition, 5.3 Gha: Sharma *et al.*, 1992). About 17% of high-latitude, 20% of mid-latitude, and 4% of low-latitude forests can be considered actively managed (see Chapter 24), but only about 100 Mha (~2%) consist of intensively managed plantations (Dixon *et al.*, 1994). The forest regions have been broadly subdivided into latitudinal zones (i.e., the tropical, temperate, and boreal zones).

Forests are ecosystems in which trees interact with each other, with other plants like shrubs and grasses, and with animals or other heterotrophic organisms such as insects or fungi. At a broad scale, forest structure is modified by processes ranging from almost continuous change due to the death of individual trees and the subsequent recruitment of seedlings, to catastrophic events such as fire, insects, wind-fall or logging that kill whole stands of trees simultaneously. At any given moment, a forest represents the outcome of long-lasting past processes, often covering many centuries.

As components of the global climatic system, forests play a major role in the present and projected future carbon budget, since they store about 80% of all aboveground and 40% of all belowground terrestrial organic carbon (e.g., Melillo *et al.*, 1990; Dixon *et al.*, 1994) and can act as sources through deforestation and degradation, as well as sinks through forestation and possibly enhanced growth (see Chapter 23 on the role of forests for mitigation of greenhouse gas emissions). Moreover, forests can directly affect the climate system from local up to continental scales: They influence ground temperatures, evapotranspiration, surface roughness, albedo, cloud formation, and precipitation (e.g., Henderson-Sellers *et al.*, 1988; Gash and Shuttleworth, 1991).

Forest ecosystems respond to environmental changes with time constants ranging from hours to decades and up to millennia (see Box 1-1); they are among the components of the biosphere that respond most slowly to climatic change. The role of forest dynamics in the global climatic system is likely to be long lasting, complex, and difficult to predict. Because of their longevity and because adaptive measures, such as replacement of species, are harder to implement than in agricultural systems, forests may be particularly vulnerable to climatic change.

Sections 1.2.1 and 1.2.2 present assessments of direct forest responses to climatic change, including possible secondary effects on forest pests, fire, and other issues, which may cause forests

Box 1-1. Scales and Equilibrium Assumptions

Climatic changes affect forests on spatial scales ranging from leaves to the canopy and on temporal scales from minutes to centuries; relevant climatic changes occur at all levels, from short-term weather fluctuations creating disturbances (such as frosts) to longer-term changes in average climatic conditions (such as moisture availability or the length of the growing season) or the frequency of extreme events (such as droughts, fires, or intense storms). Current climate models (GCMs) do not fully match these levels, since they are best at simulating average conditions at a relatively coarse spatial resolution and are usually not yet run for longer than a century. Changes in frequencies of extreme events are highly uncertain, as are local-scale climate changes, although both are of high relevance to forests.

Some of the limitations caused by this problem can be overcome in local analyses using downscaling techniques (e.g., Gyalistras *et al.*, 1994), but for global applications the implicit assumption must be made that the probability of extreme events will remain unchanged. Most transient changes in the structure of forests, such as the decline of certain tree species, are driven by a combination of climatic changes and are modified by local, biological interactions acting on temporal scales ranging from months to centuries. It is currently very difficult, therefore, to assess the likely rates of climate-driven, transient change in forests. However, possible future equilibrium conditions can be more adequately predicted.

Equilibrium projections of forest responses implicitly assume the climate to have stabilized at a new steady state, which is not likely to occur soon in reality. However, GCM-derived climate scenarios arbitrarily held constant (e.g., for 2050) allow an assessment of the direction and magnitude of the expected change. Equilibrium projections for future forests, therefore, represent conservative interpretations of minimal changes likely to occur sooner or later and hence include the potential of even greater biospheric changes than the ones currently simulated by the forest models.

Box 1-2. Temperature Thresholds

Trees have widely differing responses to temperature. Some tropical tree species suffer chilling injury at temperatures below +12°C (Lyons, 1973; Lyons *et al.*, 1979), whereas species of colder regions can survive -5°C without ice formation but are sterile at lower temperatures. Classic examples for this phenomenon are *Ilex* and *Hedera* (Iversen, 1944). Broad-leaved evergreen perennials can survive to a limit of about -15°C by supercooling, whereas broad-leaved deciduous trees can supercool to about -40°C (Arris and Eagleson, 1989). Evergreen needle-leaved trees can survive to about -60°C, below which only deciduous species survive. Apart from these killing temperatures, many species require certain minimum numbers of degree days to complete essential life-cycle processes such as bud initiation, pollen formation, flowering, or others (Stern and Roche, 1974). Others require particular sequences of cool temperatures to become frost-hardy at the optimum time and a minimum duration of chilling temperatures to break winter dormancy (Cannell, 1990). Insect pests and other biotic agents that affect forest health may have critical threshold subzero temperatures for winter survival and thermal times to complete a generation. Warming may have positive effects on the growth of many trees and their survival, but by being beneficial to insect pests it also may reduce tree survival or put cold-adapted species at a competitive disadvantage.

either to grow more vigorously or to decline[1] in a changing climate. These assessments are based on the current general understanding of the basic ecophysiological and ecological responses; the latter will be addressed on levels ranging from the stand to the globe. In the three remaining sections, we summarize more specific effects in the tropical, temperate and boreal forest zones.

1.2. Climate and Forests

1.2.1. *Sensitivities to Expected Climate Change*

Forests are highly dependent on climate in their function (e.g., growth) and structure (e.g., species composition). Forest distribution is generally limited by either water availability or temperature. The ratio of actual evapotranspiration (the amount allowed by available precipitation) to potential evapotranspiration (the amount the atmosphere would take up if soil moisture were not limiting) determines the maximum leaf area index that can be supported (Woodward, 1987). Forests are also usually absent where the mean temperature of the warmest month falls below 10°C (Köppen, 1936) or where the temperature sum above a 5°C threshold is less than 350 degree-days (Prentice *et al.*, 1992).

The survival of many species depends critically on temperature thresholds ranging from +12° to -60°C (e.g., Woodward, 1987; Prentice *et al.*, 1992; Box 1-2). Many species have narrow temperature niches for growth and reproduction. A sustained increase in mean annual temperature of 1°C may cause significant changes in the species composition of stands and hence the distribution of many tree species (Davis and Botkin, 1985; see also Section 1.3). Trees are also sensitive to changes in water availability during the growing season, and leaf area indices, volume growth, and the range boundaries of most tree species are strongly related to water availability (Holdridge, 1967; Hinckley *et al.*, 1981; Gholz, 1982; Austin *et al.*, 1990; Stephenson, 1990).

In addition to thresholds for growth, reproduction, and survival at a given site, there are limitations to the rate at which species can migrate unassisted. Current projected rates of climatic change may exceed these thresholds, as discussed in Section 1.3.5. Climatic warming and associated lower humidities and increase in the frequency and severity of droughts would increase the incidence and severity of wildfires, especially in the boreal region. Changes in fire or storm frequencies are likely to have major impacts on the composition, age-distribution, and biomass of forests (see Sections 1.5.4.5 and 1.6.4.4).

1.2.2. *Expected Climatic Changes in Forested Areos*

Future forest characteristics are likely to depend on a few specific aspects of the range of climatic changes that could occur. The most relevant are the following:

- Changes in the regional or seasonal pattern of climate, such as the temperature increases that are expected to be greatest at high latitudes, and there, greatest in winter (Greco *et al.*, 1994). Due to this, impacts on forests at high latitudes may be greater than elsewhere.
- Water shortages during the growing season. Decreasing summer precipitation together with increased evaporative demand would lead to decreases in soil water, especially in many mid-latitude regions where water is most critical for growth. It is important to note that water shortages can develop even with unchanged rainfall amounts, due to increasing temperatures causing increased evaporative demand. We expect significant regional variation, with water availability changing only marginally in some regions and improving in others, whereas in many other regions water availability may decrease drastically.

[1] Decline is defined here as "an episodic event characterized by premature, progressive loss of tree and stand vigor and health over a given period without obvious evidence of a single clearly identifiable causal factor such as physical disturbance or attack by an aggressive disease or insect" (Ciesla and Donaubauer, 1994).

- Changes in climate forcing are expected to be one or two orders of magnitude faster than rates of climatic change experienced by forests during most of the past 100,000 to 200,000 years, except, perhaps, during the Younger Dryas Event 10,000 years ago (Dansgaard *et al.*, 1989; Webb III and Bartlein, 1992; Gates, 1993). Such rapid climatic change would have particular impacts on forests. For example, there may be forest decline, interruption of tree life cycles, loss of slowly migrating species, and increasing abundance of more aggressive, early successional species.

1.3. Forests in a Changing Climate

For a detailed assessment of the effects of a changing climate on forest ecosystems, it is necessary to investigate this response to the simultaneous changes in several climatic variables (e.g., temperature, moisture availability, and ambient CO_2 concentrations). Current understanding of ecological relationships and ecophysiological mechanisms allows a comprehensive study of forests at three hierarchical levels of scale, connecting temporal and spatial resolution to the nature of the processes that are being considered (Table 1-1).

At the ecophysiological level, plant organs like stomata and leaves respond almost instantaneously to their environment. This mainly affects forest functions, such as net primary productivity. Some structural aspects, such as leaf area, may respond over a number of years, whereas others, such as species composition, may take centuries to respond to altered conditions. Typically, each species or plant functional type (PFT) is affected differently by climatic change: Some species or PFTs will remain unaffected, some will become more and others less competitive (Smith *et al.*, 1993). Dynamic forest models can be used to simulate this transient behavior of forests (e.g., Shugart, 1984; Prentice *et al.*, 1993). Landscape-scale processes such as the lateral interactions between neighboring patches (e.g., migration or fire) play an important role for possible changes in the local to regional pattern of many forest ecosystems. However, they become less relevant when aggregated to national or continental assessments. At the global level, it is currently possible to investigate only how climatic change might affect the potential geographic equilibrium distribution of biomes—i.e., biogeographic regions (e.g., Emanuel *et al.*, 1985; Prentice *et al.*, 1992)—or to study the major fluxes of trace gases into and out of these biomes (Melillo *et al.*, 1993; Plöchl and Cramer, 1995), with research underway on dynamic modelling (see also Chapter 9, *Terrestrial Biotic Responses to Environmental Change and Feedbacks to Climate*, in the Working Group I volume).

The current models can be used with climatic inputs generated by general circulation models (GCMs) for future climate scenarios, including regionally differentiated, high-resolution scenarios (e.g., Gyalistras *et al.*, 1994). However, current understanding of the physical and biological interactions between environment and organisms is still rather limited, so these techniques enable us only to project future responses as consequences of given assumptions and scenarios and not to make precise forecasts.

1.3.1. Ecophysiological Responses

1.3.1.1. Tree Responses to Temperature and Water Availability

When they are well supplied with water, trees of most temperate and boreal species respond to increased temperature (e.g., from year to year, or when planted at a slightly warmer location) by growing faster (e.g., Cannell *et al.*, 1989; Beuker, 1994), and they reach their largest mass near the warmest boundaries of their geographic ranges (Korzukhin *et al.*, 1989). Generally, there is a positive correlation between net primary productivity and temperature (Box, 1978; Kauppi and Posch, 1985; Kokorin *et al.*, 1993; Morikawa, 1993) or between net primary productivity and actual evapotranspiration (Rosenzweig, 1968; Raich *et al.*, 1991).

However, these potential growth responses to warming may be constrained by other factors. Increasing temperature increases evaporative demand; if rainfall does not increase, more severe water stress will result, which will adversely affect growth and may increase the risk of drought and fire. To what extent this can be compensated by increased water-use efficiency due to increasing CO_2 concentration is not yet known (see Section 1.3.1.2 and Chapter A). Photoperiodic limitations might also

Table 1-1: Hierarchical levels at which it is currently possible to study and model the impact of climatic change on forest ecosystems. Note that transient responses of trees and forests can currently only be studied at the first two levels.

Level	Focus	Time Resolution	Time Scope	Space Resolution	Space Scope
Ecophysiological Processes	Plant Metabolism	min..h	1..10 yr	0..100 m	locations
Individuals, Populations, Forest Stands	Ecosystem Dynamics	d..yr	$1..10^3$ yr	~100 m	regions to continents
Plant Functional Types, Vegetation, Vegetation Complexes, Biomes	Biospheric Equilibrium	–	$\geq 10^3$ yr	$\sim 10..10^3$ km	globe

apply in areas where temperature becomes warm enough for tree growth (e.g., Heide, 1974, 1993), and increasing temperature might increase the range of insect pests, which could cause considerable damage.

GCMs suggest a globally averaged increase in precipitation of about 2.5% per degree warming (Mitchell *et al.*, 1990; Greco *et al.*, 1994), which may not be sufficient to meet the increased water requirements of forests. Most GCMs indicate significant declines in net soil moisture over continental areas during the growing season (e.g., Manabe and Wetherald, 1987; Greco *et al.*, 1994). There are likely to be considerable regional differences, however, with some regions likely to receive increased rainfall sufficient to meet increased evaporative demand and other regions receiving even less rainfall than at present. Because the present distribution of species and plant functional types is strongly determined by the total (Holdridge, 1967; Box, 1981; Hinckley *et al.*, 1981; Austin *et al.*, 1990) and seasonal availability of water (Stephenson, 1990; Prentice *et al.*, 1992), any changes in water availability are likely to greatly affect the distribution of species (see Section 1.3.2).

1.3.1.2. Tree Responses to Increased CO_2 Concentration

The importance of CO_2 fertilization continues to be controversial (e.g., Körner, 1993; Idso and Idso, 1994; see also Chapter A). While the response of photosynthesis to CO_2 concentration can be readily observed at the single-leaf or isolated plant level (Kimball, 1983; Cure and Acock, 1986; Mooney *et al.*, 1991; Luxmoore *et al.*, 1993; Wullschleger *et al.*, 1995), it has been argued that this initial benefit may be negated by the various feedbacks in the plant and soil (e.g., Bazzaz and Fajer, 1992; Díaz *et al.*, 1993; Körner, 1993). Quantification of some of these feedbacks has been attempted (e.g., Comins and McMurtrie, 1993; Kirschbaum *et al.*, 1994) but has not yet been possible for the great diversity of natural habitats, in which most of the feedback effects are still inadequately understood and poorly quantified. Experimental approaches have not yet resolved this controversy because of the enormous costs and technical difficulties involved. Only a small number of open-air CO_2 enrichment experiments have been conducted with mature natural populations—and none on forests.

Because atmospheric CO_2 has already increased from a preindustrial concentration of about 280 ppmv to about 360 ppmv at present, increased growth should be observable in the growth of plants under natural conditions. However, the evidence from tree-ring chronologies is unclear, and no generalizations can be made (Innes, 1991). Where growth increases have been observed, part or all of that probably could be explained by more favorable temperatures, water relations, successional age, or nitrogen fertilization by moderate levels of industrial pollution (Innes, 1991; Luxmoore *et al.*, 1993).

When plants have access to limiting amounts of water, growth is limited by the amount of CO_2 that can be obtained in the diffusive gas exchange during photosynthesis. Once the available water has been used up, tissue water potentials fall below threshold levels and growth ceases. Growth under these conditions is determined by the amount of available water multiplied by water use efficiency (WUE). Because WUE can be greatly enhanced by increased CO_2 concentration (Rogers *et al.*, 1983; Tolley and Strain, 1985; Morison, 1987; Eamus and Jarvis, 1989), relative plant responses to increases in ambient CO_2 should be most pronounced under water-limited conditions (e.g., Gifford, 1979; Allen, 1990). While increasing CO_2 concentration may be beneficial for plant growth, some researchers rank it of less importance than changes in temperature and/or precipitation, which can have large impacts when critical thresholds of drought, chilling, or degree-days are reached (e.g., Solomon, 1988).

1.3.1.3. Carbon Storage and Nutrient Availability

Although increasing temperature may lead to higher net primary productivity (NPP), net ecosystem productivity (NEP) may not increase, and may even become negative, because warmer temperatures also greatly stimulate soil organic matter decomposition (e.g., Raich and Schlesinger, 1992; Lloyd and Taylor, 1994; Kirschbaum, 1995; Chapter A). This could release large amounts of CO_2 to the atmosphere (e.g., Jenkinson *et al.*, 1991; Kirschbaum, 1993, 1995; Schimel *et al.*, 1995; Chapter 9, *Terrestrial Biotic Responses to Environmental Change and Feedbacks to Climate*, in the Working Group I volume). However, the direct effect of increasing CO_2 concentrations may partly offset or in some cases even reverse this effect and make NEP positive.

Enhanced decomposition of soil organic matter also should have the effect of mineralizing nutrients—especially nitrogen and phosphorus—that are held in soil organic matter and making them available for plant growth (e.g., Shaver *et al.*, 1992; Melillo *et al.*, 1993). This is likely to be of greatest importance in cool regions of the world, which are mostly nitrogen-limited and often contain large amounts of organic matter (Post *et al.*, 1982). This could sometimes lead to an increase in total carbon storage in systems if nutrients are redistributed from components with low C:N ratios (i.e., soil organic matter) to components with high C:N ratios (i.e., woody stems) (Rastetter *et al.*, 1992; Chapter 9, *Terrestrial Biotic Responses to Environmental Change and Feedbacks to Climate*, in the Working Group I volume). In industrialized regions, nitrogen deposition from the atmosphere may enhance NPP and NEP, leading to increased total carbon storage in forest ecosystems (Kauppi *et al.*, 1992), provided deposition has not reached levels that cause forest decline (Durka *et al.*, 1994).

1.3.2. Species Distributions

Species have responded individually to past environmental changes (Huntley and Birks, 1983; Davis and Zabinski, 1992; Solomon and Bartlein, 1992; Gates, 1993). The set of all possible environmental conditions in which a given species survives

Box 1-3. Ecological Niches and Climatic Change

Any species' survival is influenced by many factors, and the set of environmental conditions in which it can exist and reproduce is called its niche. A distinction must be made between a species' fundamental niche and its realized niche (Hutchinson, 1957; Malanson *et al.*, 1992). The fundamental niche encompasses all environmental conditions in which a species could potentially grow and reproduce with its specific physiological characteristics. The realized niche encompasses those conditions in which a species is actually found. The latter is usually a subset of the fundamental niche due to competition by other species (see Chapter A). Only rarely does the realized niche coincide with the fundamental one (Woodward, 1987; Booth *et al.*, 1988; Austin *et al.*, 1994). Examples of typical environmental factors that determine a species' niche are temperature and precipitation (see Figure 1-1).

Species with narrow niches are potentially very sensitive to climatic changes. A sustained temperature increase of only 1°C could have a major effect on the probability of occurrence of many species (e.g., Arolla pine, Figure 1-1), and in some instances a temperature increase of 2°C can be sufficient to change the environment for some species from very suitable to totally unsuitable (e.g., Whitehead *et al.*, 1993).

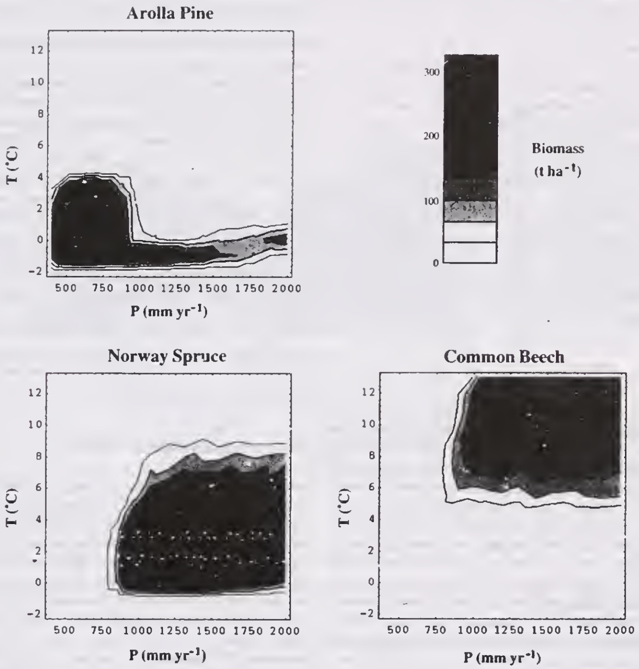

Figure 1-1: Simulated realized niches of three tree species [*Pinus cembra* L. (Arolla Pine), *Picea abies* (L.) KARST. (Norway Spruce), and *Fagus sylvatica* L. (Common Beech)] plotted as biomass versus annual means of temperature (T) and precipitation (P) (after Bugmann, 1994). The realized niches can be rather narrow (e.g., Arolla pine) and are usually smaller than the corresponding fundamental niches. For example, Norway spruce can easily be planted in climatic conditions where it naturally would be outcompeted by beech.

and reproduces (but without evolving—that is, changing its inherited characteristics such as physiological traits), is called its fundamental ecological niche (Hutchinson, 1957; Malanson *et al.*, 1992). In field conditions, species often survive only in a subset of the fundamental niche, the realized niche (Grubb, 1977; Booth *et al.*, 1988; Malanson *et al.*, 1992), owing especially to competitive interactions with other species (see Box 1-3).

With rapid climatic change, conditions may become unsuitable to complete one or more stages of the life cycle, especially if some climate variables were to change significantly more than other variables. For example, pollen and seed development require minimum heat sums and are sensitive to frosts (Stern and Roche, 1974). Seedlings are particularly vulnerable to short-term droughts, saplings to the presence or absence of sunlight, and mature trees to the availability of growing-season soil water. Populations could appear quite healthy while losing the ability to complete their life cycles.

Trees whose seedlings can now survive at a particular site will grow into adults in climates that may be unsuitable in 50–100 years; conversely, adults that could grow in an area in 50–100 years time must grow from seedlings that may be unable to survive current climatic conditions at those sites. A net ecosystem-level impact may be the loss of slow-growing species and the selection of species that complete their life cycles more quickly, such as early successional trees and shrubs. The ability to reach reproductive maturity in a short time favors early successional species that grow in full sun, whereas slower-growing species that begin their life cycles as understory species under closed canopies may be lost. Some model simulations have indicated that this opening of closed forests could result in the loss of three quarters of the trees and aboveground carbon in current temperate-zone forests (e.g., Solomon, 1986).

1.3.3. Transient Responses in Species Compositions

Concerns about the future of forest ecosystems relate not only to the geographic distribution of areas potentially suitable for forests and the performance of trees under different environmental conditions but also to the effect of climate change on the functioning and structure of ecosystems during the transient phase. For instance, it is well known that changing ambient conditions can reduce growth in forest ecosystems (e.g., Solomon and Webb III, 1985; Shugart *et al.*, 1986; Solomon, 1986; Woodwell, 1987; Prentice *et al.*, 1991b; Botkin and Nisbet, 1992; Davis and Zabinski, 1992). Moreover, the magnitude of climate change will subject many species assemblages, within a life cycle of their main species and in most of their distribution area, to climates that now occur outside their current ecological range (e.g., Solomon *et al.*, 1984; Roberts, 1989; Davis and Zabinski, 1992).

The transient response of species to such climatic changes can currently be assessed only with forest succession models (see Box 1-4). Despite some of their deficiencies (e.g., Moore, 1989; Bonan, 1993; Bugmann and Fischlin, 1994; Fischlin *et al.*, 1995), these models can be used to project transient changes in species composition of selected forest types for scenarios of climatic change in the past (Solomon *et al.*, 1981; Lotter and Kienast, 1992) or future (Pastor and Post, 1988; Kienast, 1991; Friend *et al.*, 1993; Bugmann, 1994; Bugmann and Fischlin, 1994; Smith *et al.*, 1994; see Box 1-4). These simulations suggest that climate change could cause widespread tree mortality within a few decades (Solomon *et al.*, 1984; Solomon, 1986; Solomon and West, 1987; Pastor and Post, 1988; Kienast, 1991; Prentice *et al.*, 1991b; Bugmann, 1994; Bugmann and Fischlin, 1994). Solomon and Bartlein (1992) and Pastor and Post (1993), for example, show how lags in population responses to climatic change could result in transient decreases in NPP before better-adapted species eventually replace the original vegetation and result in enhanced growth. It also should be noted that many simulations show species compositions that are not present in existing forests (Bugmann, 1994; Bugmann and Fischlin, 1994; Smith *et al.*, 1994).

Regrowth of better-adapted species or forest types requires many decades to centuries (Dobson *et al.*, 1989; Kienast and Kräuchi, 1991; Bugmann and Fischlin, 1994). Consequently, regions with forests in decline could release large amounts of carbon (e.g., Smith and Shugart, 1993), producing a large transient pulse of CO_2 into the atmosphere (e.g., Neilson, 1993; Chapter 9, *Terrestrial Biotic Responses to Environmental Change and Feedbacks to Climate*, in the Working Group I volume). Whereas some authors have estimated this carbon pulse from aboveground carbon alone to fall within a range of 0.1 to 3.4 Gt yr^{-1} for the annual flux, or 10 to 240 Gt for the accumulated pulse (King and Neilson, 1992), others have estimated a total carbon pulse from above and belowground C as high as 200 to 235 Gt, to be released to the atmosphere during a few decades to a century (see Section 1.3.4; Neilson, 1993; Smith and Shugart, 1993). Such responses, although debatable in their magnitude, are plausible because climatic changes also have been implicated in past episodes of forest and species decline (Cook *et al.*, 1987; Hamburg and Cogbill, 1988; Johnson *et al.*, 1988; Auclair *et al.*, 1992).

1.3.4. Potential Biome Distributions

Patch dynamics models cannot currently be used to simulate the transient behavior of forests in a changing climate on a global scale. This is because they require a large set of species-specific information that is not available from all regions of the world, especially not from the tropical zone. However, on the biospheric level (Table 1-1), several static global vegetation models have recently become available that enable us to make estimates of vegetation-climate equilibria (Box, 1981; Emanuel *et al.*, 1985; Prentice *et al.*, 1992; Smith *et al.*, 1992a, Cramer and Solomon, 1993; Leemans and Solomon, 1993; Monserud *et al.*, 1993b; Tchebakova *et al.*, 1993; Leemans and van den Born, 1994; Neilson *et al.*, 1994) based on earlier related studies (e.g., Köppen, 1936; Holdridge, 1947; Woodward, 1987).

Given any past or present climate, such vegetation models can be used to map the distribution of biomes (e.g., Prentice *et al.*,

Box 1-4. Forest Succession Models

Most forest succession models are based on the gap dynamics hypothesis (Watt, 1947; Bray, 1956; Shugart, 1984). They simulate the establishment, growth, and death of individual trees as a mixture of deterministic and stochastic processes within small—often $^1/_{12}$ ha—patches and average the actual forest succession at the ecosystem level from the successional patterns simulated for many individual plots (Shugart, 1984). Earlier work on the potential effects of climatic change on forests had to rely on spatial correlations between forest composition and climatic variables (e.g., Davis, 1986). Similarly, models that do not explicitly account for the differential effects of climatic change on different species may give optimistic projections of the effect of climatic change on ecosystem productivity. The more complex succession models that include the feedbacks between climate and ecosystem processes provide a more pessimistic outlook (see Figure 1–2).

On the other hand, most of these models do not include direct effects of increasing CO_2 concentration, which can ameliorate projected forest decline (e.g., Post *et al.*, 1992). Also, because of the limited availability of data on the fundamental niche of most species, these models are parameterized with information about the realized niche only (Austin, 1992). It has been argued that this might cause succession models to overestimate the extent of forest decline during the transient phase (e.g., Malanson *et al.*, 1992). Despite these caveats, patch models are the best tools currently available to study transient effects during climatic and other changes. Their simulations for current forests in response to past climatic changes provide fairly realistic assessments of likely future conditions (e.g., Solomon and Bartlein, 1992; Bugmann, 1994), although they cannot be interpreted as actual forecasts.

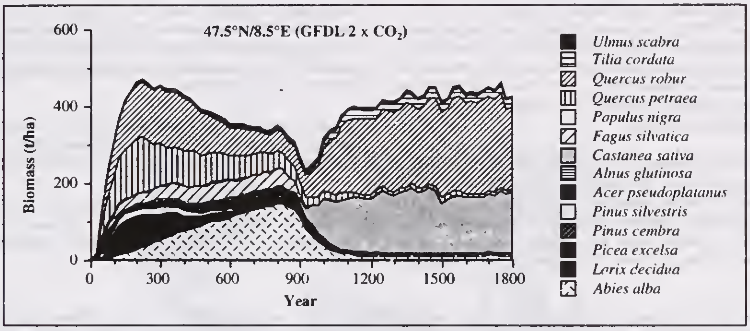

Figure 1-2: Transient response in species compositions simulated by the model FORCLIM-E/P (Bugmann, 1994; Fischlin *et al.*, 1995) at a site in Switzerland (47.5°N/8.5°E) under current climatic conditions (years 0–800) and under a scenario of climatic change derived from output of the GFDL GCM (years 900–1,800). A linear change of climatic parameters was assumed for the years 800–900. The graph shows the average cumulative biomass from 200 simulation runs (after Bugmann and Fischlin, 1996).

1992) or biospheric carbon storage (e.g., Solomon *et al.*, 1993) and to compare the simulated patterns with the present vegetation as provided by the few available global databases (Matthews, 1983; Olson *et al.*, 1983); see Figures 1-3, 1-5 (top), 1-6 (top), and 1-7 (top). Although these models are at an early stage of development (Leemans *et al.*, 1995), there is good statistical agreement between simulated and observed distributions of vegetation classes (e.g., Prentice *et al.*, 1992), except in areas where agriculture dominates. Although global models never can be strictly validated, their recent development toward inclusion of improved bioclimatic driving variables and mechanistic response functions offers increasing confidence in the magnitude of the results they generate. More about the nature and limitations of these models can also be found in Chapter 15.

The more recent models, such as BIOME (Prentice *et al.*, 1992), MAPSS (Neilson *et al.*, 1992), or TVM from IMAGE 2.0 (Leemans and van den Born, 1994), all attempt to simulate vegetation distribution considering ecophysiological traits and their relationship to particular climatic variables. This makes it possible to generate projections of vegetation distributions under past (Prentice, 1992; Prentice *et al.*, 1994; Figure 1-4), present [Prentice *et al.*, 1992; Neilson, 1993; Solomon *et al.*, 1993; Prentice and Sykes, 1995; Figures 1-5 (top), 1-6 (top), and 1-7 (top)], or future climates [Cramer and Solomon, 1993;

Leemans and Solomon, 1993; Neilson, 1993; Solomon *et al.*, 1993; Leemans *et al.*, 1995; Figures 1-5 (bottom), 1-6 (bottom), and 1-7 (middle)]. Apart from being used for climate-change impact assessment studies, they are now also used as a dynamic representation of the land surface for sensitivity studies of GCMs (see Claussen, 1994; Claussen and Esch, 1994; Chapter 9, *Terrestrial Biotic Responses to Environmental Change and Feedbacks to Climate*, in the Working Group I volume).

The models differ in their emphasis on particular processes and relationships (Leemans *et al.*, 1995). For example, BIOME (Prentice *et al.*, 1992) includes physiologically important aspects such as seasonality and moisture balance, and is based on PFTs, which to some extent simulate interspecific competition. MAPSS, on the other hand, couples the rate of transpiration to the conductance of the canopy by simulating maximum leaf-area index and stomatal conductance (Neilson *et al.*, 1994; Neilson and Marks, 1994). The latter makes it possible to incorporate ecophysiological responses such as CO_2 fertilization and WUE, but all species-specific information is lumped. These models use somewhat different vegetation classification schemes [e.g., compare Prentice *et al.* (1992) and Neilson (1993)], which usually makes direct comparisons possible only if some classes are aggregated (compare Figures 1-5 to 1-7 and Table 1-2 with Prentice *et al.*, 1992; Neilson, 1993; or Leemans and van den Born, 1994). Consequently, the vegetation distributions projected for a changed climate may differ substantially (Table 1-2).

One of these models, IMAGE 2.0, also has been used to incorporate the effect of climate change superimposed to the impacts of land-use changes (Alcamo, 1994; Figure 1-7). Its vegetation part (Leemans and van den Born, 1994) makes it possible to assess global forest distributions for the present [Figure 1-7 (top)] as well as the future [e.g., according to the conventional wisdom scenario of Figure 1-7 (middle and bottom)]. However, the potential natural vegetation is essentially modeled in a manner similar to BIOME (Prentice *et al.*, 1992).[2]

Although none of these models deals with transient forest responses, they offer the advantage of providing quantitative estimates for changes in a future climate on the scale of the distinguishable vegetation classes (Table 1-2; Figures 1-3 to 1-7). Due to the limited range of vegetation classes—BIOME and IMAGE, for instance, distinguish 20 (Prentice *et al.*, 1992; Leemans and van den Born, 1994; Prentice *et al.*, 1994); MAPSS distinguishes 33 (Neilson, 1993)—the projected changes (Table 1-2) tend to underestimate actual changes. Changes within a class remain by definition undetected and would have to be modeled by means of more detailed vegetation models.

The total area currently forested is likely to change significantly, if the changes occur according to any of the three models, from its present to a new vegetation class (Table 1-2, D). These estimates range from small changes [e.g., 7.5% (tropical rain forest)] to large ones [e.g., 65.1% (boreal forest)]—both estimated using the BIOME model. Net changes (Table 1-2, D*)—that is, the difference between the total forested area in the future versus the current climate—range from losses of 50.0% (IMAGE/TVM—tropical dry forest) to gains as large as 22.2% (MAPSS—tropical dry forest).

Except for MAPSS in the version shown here (i.e., without considering the partially compensating, increased WUE; Neilson and Marks, 1994), for the tropical zone models project a net

[2] More information about this class of biosphere models can be found in Chapter 9, *Terrestrial Biotic Responses to Environmental Change and Feedbacks to Climate*, in the Working Group I volume, and in Chapters 15 and 24 of this volume

Table 1-2: Likely changes in forested areas (Mha) within four biogeographical zones according to three different vegetation models: BIOME (Prentice et al., 1992), MAPSS (Neilson, 1993), and terrestrial vegetation model (TVM) (Leemans and van den Born, 1994) from IMAGE 2.0 (Alcamo, 1994).

	BIOME 2 x CO_2 (GFDL)			MAPSS 2 x CO_2 (GFDL)			IMAGE-TVM 2050			Mean	
Forest Type	**D**	**s_o**	**D***	**D**	**s_o**	**D***	**D**	**s_o**	**D***	**%D**	**%D***
Tropical Rain	57	706	19	281	1243	-234	129	296	-129	18.8	-14.4
Tropical Dry	153	640	-2	353	528	196	324	294	-309	37.2	-9.3
Temperate	346	1607	544	1007	1039	-155	388	583	-65	35.7	4.5
Boreal	952	511	-379	1231	1117	-529	42	1128	-33	40.4	-17.1

Notes: The first two models are used with a 2 x CO_2 equilibrium climate-change scenario generated by the GFDL GCM (Wetherald and Manabe, 1986). TVM from IMAGE 2.0 generated the changed climate internally, based on comparable assumptions (Conventional Wisdom Scenario) about greenhouse gas concentrations (Alcamo, 1994) and land-use changes as driven by population developments. All numbers relate to a potential forest vegetation in equilibrium with the climate, a steady state that is unlikely to be reached for many centuries. All figures were compiled by using the maximum number of vegetation classes as supported by the models (i.e., more than the 10 classes shown in Figures 1-3 to 1-7). D = Total forested area in transition from current type into a new one; s_o = Total forested area remaining within the same vegetation class; D* = Net change (data compiled by R. Leemans). The last two columns show means over all models as percentages of the currently forested area.

Figure 1-3: Present observed distribution of global vegetation complexes redrawn from the database compiled by Olson *et al.* (1983). For comparison, the vegetation classes have been aggregated to the same classification system as that used for all other model results shown here.

Figure 1-4: Past equilibrium vegetation according to BIOME (Prentice *et al.*, 1992) during the last glacial maximum [i.e., 18,000 years BP (Prentice *et al.*, 1994)]. The climate used for this simulation is derived from a GCM (not from paleoecological data, as this would lead to a circular argument). Note that according to this simulation, boreal forests cover only about 20% (Solomon *et al.*, 1993) of today's potential distribution (Prentice *et al.*, 1994).

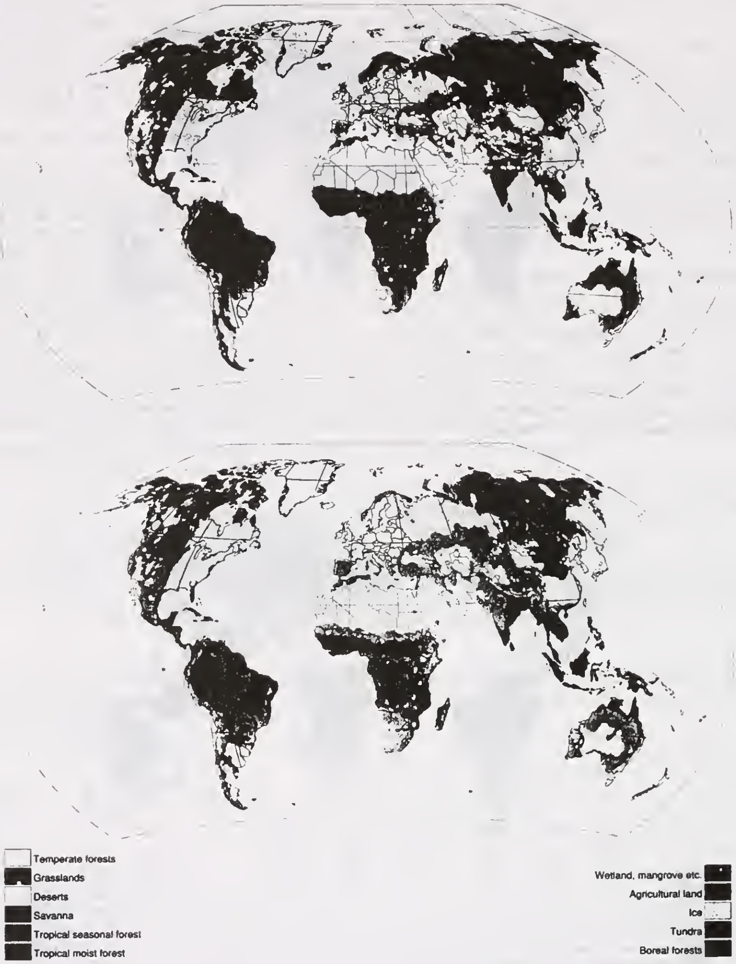

Figure 1-5: Present (top) and future (bottom) potential natural vegetation according to the BIOME model (Prentice *et al.*, 1992; Prentice *et al.*, 1994). The present climate is given by the IIASA climate database (Leemans and Cramer, 1991). The projected shifts in the boundaries of the vegetation classes are due to climatic changes as projected by the difference between a GFDL GCM control run and a 2 x CO_2 scenario (Wetherald and Manabe, 1986). They represent responses of plant functional types to cold tolerance, chilling requirements, and heat and [illegible] of global vegetation (Solomon *et al.*, 1993; Prentice and Sykes, 1995).

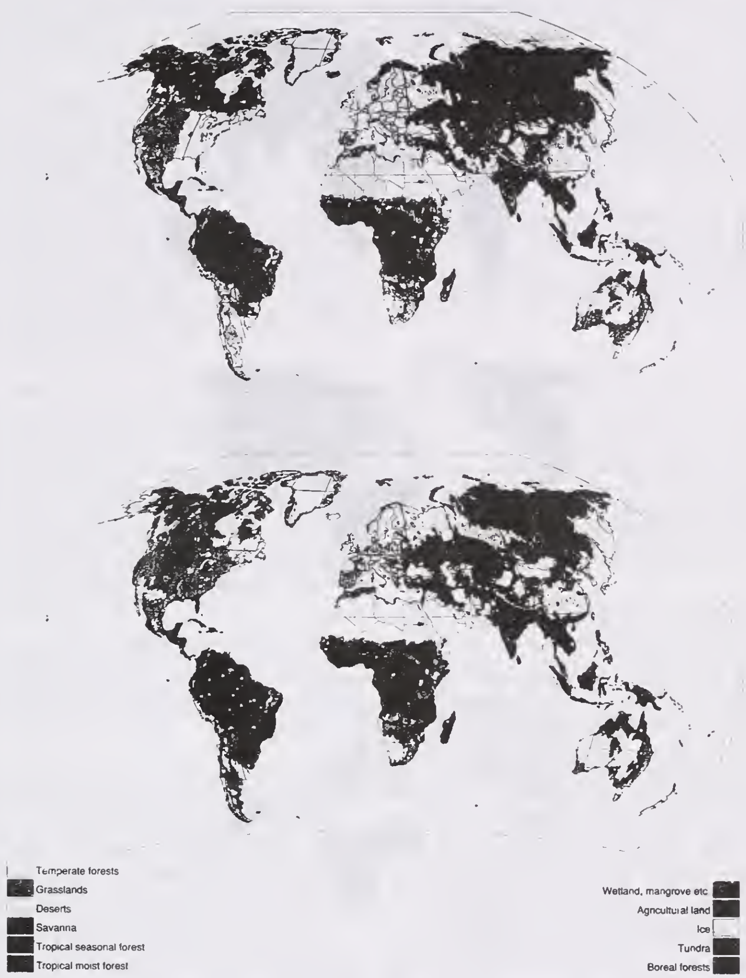

Figure 1-6: Present (top) and future (bottom) equilibrium potential natural vegetation according to the MAPSS model (Neilson, 1993). The present climate is given by the IIASA climate database (Leemans and Cramer, 1991). The projected shifts in the boundaries of the vegetation classes are due to climatic changes as projected by the difference between a GFDL GCM control run and a 2 x CO_2 scenario (Wetherald and Manabe, 1986). The model simulates climate responses due to a simulated steady-state leaf-area index, calculated from a site water and heat balance submodel (Neilson, 1993).


Temperate forests
Grasslands
Deserts
Savanna
Tropical seasonal forest
Tropical moist forest
Wetland, mangrove etc.
Agricultural land
Ice
Tundra
Boreal forests

gain in the potential area of forest distribution. Mainly IMAGE-TVM projects large net losses in the tropical rainforests. These losses are not due to climatic change, however, but are mainly caused by deforestation and other land-use changes (Zuidema *et al.*, 1994).

Although BIOME and MAPSS indicate relatively small net changes (Table 1-2, D*) in tropical dry forests, the actual changes encompass large gross losses (D), which are compensated by similarly large gross gains (not shown in Table 1-2). This is also partly true for the temperate zone, where MAPSS, for example, projects only relatively small net losses (D*); however, the associated gross losses (D) irrespective of gains (not shown) are more than six times larger. Mapped distributions indicate that temperate forests are likely to replace a large area of boreal forest, mainly due to the increase in winter temperatures (Figures 1-5 and 1-6). This allows temperate-zone vegetation to expand poleward into regions from which it is currently excluded by the -40°C threshold for the coldest month (Figures 1-5, 1-6, and 1-7).

The boreal regions, especially, are expected to undergo large vegetation shifts, with both MAPSS and BIOME projecting large changing areas (Table 1-2, D). Both models show large losses in area for current boreal forests, despite their encroachment into current tundra. Shrinkage in total area due to the geographically limited poleward shift leads to a net loss between 379 Mha (25.9%) and 529 Mha (22.5%).[3] The IMAGE model is an exception in this case; it projects much smaller losses of only 33 Mha (2.9%) (Figures 1-5, 1-6, and 1-7). This is mainly due to the structure of the model, in which vegetation change is primarily driven by human land use—which is not an important factor in the boreal zone.

In summary, all models suggest that the world's forests are likely to undergo major changes in the future, affecting more than a third of tropical dry (37.2%), temperate (35.7%), and boreal (40.4%) forests. Except in the temperate zone, the models suggest that there may be a net loss of forest area (Table 1-2, %D*).

Figure 1-7: Present (top), future (middle), and differing (bottom) potential natural vegetation influenced by human land use as generated by the terrestrial vegetation module (TVM; Leemans and van den Born, 1994) from the integrated climate change assessment model IMAGE 2.0 (Alcamo, 1994). The areas shown represent a projection starting with the year 1970 (top) and the internal, dynamic changes calculated by IMAGE 2.0 by the year 2050 (middle). The bottom graphic shows the new class for all areas that are predicted to change from one to another vegetation class. The simulation results generated by IMAGE 2.0 incorporate the effect of land-use changes (e.g., deforestation) as driven by the dynamics of human populations and economic development. Note that IMAGE 2.0, unlike the other models, simulates climatic change independently from a GCM, since it generates its climate internally. The vegetational part (Leemans and van den Born, 1994) of the IMAGE model is similar to BIOME (Prentice *et al.*, 1992) and represents a mixture between a transient and a static response of vegetation to internally as well as externally generated changes.

Averaged over all zones, this net loss amounts to 9.1% of the currently forested area. This is partly due to the fact that some regions are likely to lose forests for climatic reasons, while climatic gains in other regions might not be realized due to land-use pressures (IMAGE), and some models even predict a net loss (MAPSS). Averaged over all zones and all models, the projections indicate that 33% of the currently forested area is likely to change from the current vegetation class to a new one in response to climate forcing as generated by the GFDL 2 x CO_2 scenario. Compared with other GCMs, the latter represents a medium global warming scenario.

All models tend to underestimate potential changes, since they model only transitions among a limited number of vegetation classes. More importantly, as equilibrium models, none of them reflects the asymmetry between a temporary loss and the subsequent, much slower regrowth of forests in a new climate (see Section 1.3.3).

1.3.5. Past and Future Species Migration Rates

Shifts in the distribution of forest zones take place with significant time lags. The area occupied by different forest types has been quite plastic in the past 100,000 years, responding to changing environments with changes in species associations, structural properties of stands, and areas occupied (Solomon and Webb III, 1985; Webb III and Bartlein, 1992). Unlike the Pleistocene climatic changes, which occurred over thousands of years, future climatic changes of about the same magnitude are expected to take place over 100 years or less.

The change in annual mean temperature that occurs when one moves 100 km poleward may be as high as 0.7°C in mid- and high latitudes, but less at low latitudes. For summer temperatures and toward the interior of the continents, this value may be higher. With altitude, temperature changes of about 0.5–0.7°C per 100 m are also common (see also Chapter 5). With an expected warming between 0.1 and 0.35°C per decade, this means that species would have to migrate 1.5–5.5 km toward the poles per year or increase elevation by 1.5–5.5 m per year in order to remain within similar climatic conditions. Many studies of past changes have estimated natural rates of migrations of trees ranging from 40 to 500 m per year (Davis, 1976, 1981, 1986; Huntley and Birks. 1983: Solomon *et al.*, 1984; Gear and Huntley, 1991; Torrii, 1991). Similarly, Gear and Huntley (1991) calculated from several sites in Britain migration rates for Scots pine of only 40–80 m yr^{-1}. However, for other species, such as white spruce, much faster dispersal rates of up to 1–2 km yr^{-1} also have been reported (e.g., Ritchie and MacDonald, 1986). It is not always clear whether the observed past rates were maximal rates of migration or whether they were limited by the rate at which the climate

[3] The apparent lack of coincidence between relative and absolute changes is due to different definitions of the vegetation class "boreal forest." The MAPSS model has a greater area characterized as boreal forest than the BIOME model.

changed (Prentice *et al.*, 1991a; Prentice, 1992). Nevertheless, it is unlikely that future rates of species migration could match those required by the currently expected rates of climatic change in large areas. Pollen, on the other hand, may be dispersed much faster than seeds (e.g., Ennos, 1994), so the movement of genes of different ecotypes within a species might be able to match the speed of climatic change.

Migration of a tree species involves movement of propagules to new locations, establishment of seedlings, growth of individuals to reproductive maturity (which may take from years to decades), and production of new propagules. For long-distance migration, these stages need to be repeated. Several bottlenecks may be encountered: Strong competitors along the route may suppress the completion of full life cycles or specific, mandatory biological symbionts [e.g., the right species of mycorrhizal fungi (Perry *et al.*, 1987, 1990)], or specific pollinators for cross-fertilization may be absent at some point. Seed production, in particular, often depends on a phased sequence of development over at least 2 years, including many steps from floral bud differentiation to seed ripening (Fenner, 1991). Many stages in this sequence could be disrupted by unsuitable climatic conditions (Innes, 1994): With further warming, some species may fail to be chilled sufficiently to release dormancy (Murray *et al.*, 1989; Cannell, 1990), or dormancy may be released too early, which paradoxically could result under some circumstances in greater frost damage (Hänninen, 1991). Conversely, many trees flower profusely following hot, dry conditions (Stern and Roche, 1974). Hence, differential seed production by different species may limit rates of migration and drive substantial changes in species distributions.

Since each stage of a tree's life cycle requires specific environmental conditions, rapid climatic change is less likely to offer sufficiently favorable conditions to complete complex life cycles. This is especially true for some slow-growing species. More flexible species, such as those with wider seed dispersal, or a more invasive growth habit, may be able to move to more favorable habitats, whereas less mobile species are likely to be left behind and would be at a disadvantage as their former habitat becomes climatically unsuitable. Such a decoupling of climate determinants from species and community distributions probably has occurred already many times and at many places during the last millennia (Davis, 1986). The result has been a temporary absence of certain species for hundreds and thousands of years from regions in which they were previously capable of growing. Despite this, species diversity also could be transiently enhanced during a time of change because forests might form a richer mosaic of patches, consisting of some remaining old trees and a variety of invaders that are successful because of locally more favorable conditions.

In the future, human activities may to a certain extent enhance the migration of certain species, especially that of commercially important ones. On the other hand, natural migration of all other forest species will be further hampered by the fragmentation of natural habitats by human infrastructure, farmland, or exotic tree plantations, especially at mid-latitudes.

1.3.6. Biodiversity

To date, only about 1.4–1.7 million of an estimated total of 5–30 million species have been scientifically described (Wilson, 1985, 1992; May, 1990; Ehrlich and Wilson, 1991; Erwin, 1991; Gaston, 1991; Pimm *et al.*, 1995), and fewer than 100,000 are known well (e.g., Wilson, 1988; Pimm *et al.*, 1995). About 20% of the estimated total of 250,000 plant species are woody or tree species (e.g., Groombridge, 1992; Reid, 1992; Pimm *et al.*, 1995). There is poor understanding of the factors responsible for maintenance of high biodiversity (e.g., Grubb, 1977; Stork, 1988; Groombridge, 1992; Norton and Ulanowicz, 1992; Myers, 1995; Pimm *et al.*, 1995), but it is understood that biodiversity can only be managed indirectly through habitat and ecosystem management (e.g., Wilson, 1992). In this respect, forests are of paramount importance because they harbor about two-thirds of all species on Earth (Ehrlich and Wilson, 1991); tropical forests alone harbor at least half of all species (Raven, 1988; Ehrlich and Wilson, 1991; Webb, 1995). Species diversity generally increases strongly as one moves from colder to warmer sites (e.g., Groombridge, 1992), although the reasons for that trend are not well understood. When the size of an ecosystem is reduced to about 10% of its former size, about 50% of the species originally present generally will become extinct. Based on that relationship, it has been estimated, for instance, that a temperature rise of 2°C would cause 10–50% of the animals currently extant in the boreal Great Basin mountain ranges to be lost (Dobson *et al.*, 1989).

Climatic change can affect biodiversity either directly through altering the physiological responses of species or indirectly by altering interspecific relationships (e.g., Woodward, 1987; Tallis, 1990; Peters and Lovejoy, 1992). Whenever these changes lead to a habitat degradation, biodiversity will eventually be adversely affected (e.g., Peters and Lovejoy, 1992; Vitousek, 1994). Furthermore, biodiversity is affected not only by climate change but also by deforestation and other land-use changes that cause further habitat degradation and fragmentation (Janzen, 1988; Dobson *et al.*, 1989; Wilson, 1989; Ehrlich and Wilson, 1991; Myers, 1991, 1993; Postel, 1994; Daily, 1995; Pimm *et al.*, 1995). The combination of climate change with other pressures on ecosystems produces a particularly significant threat to biodiversity due to the following reasons:

- Climate change, together with other causes of habitat degradation, may locally decrease species diversity (Peters and Darling, 1985; Romme, 1991; Myers, 1992; Peters, 1992; Daily, 1995; Pimm *et al.*, 1995; Rind, 1995). Disturbance also may create opportunities for opportunistic or pioneer species, which will become more abundant (Myers, 1993) and, over time, replace many species that are slower growing and require more stable conditions. In some cases, this may lead to a temporary increase in species diversity (e.g., Lugo, 1988; Mooney, 1988; Vitousek, 1988).
- Species may become permanently extinct when local extinction cannot be reversed by reimmigration from

surrounding areas. This problem would be most severe where the climate in a species' reserve changes from being favorable to being completely unsuitable (Peters, 1992), rendering "sanctuaries" into "traps" (Myers, 1993). Thus, an increasing fragmentation of habitats in combination with climate change may cause significant and irreversible species loss, a situation with which many of the current policies on reserves have large difficulties coping adequately (Ehrlich and Wilson, 1991; Botkin and Nisbet, 1992; Franklin *et al.*, 1992; Myers, 1992; Peters, 1992).

Although the effects of climatic change on biodiversity are still poorly understood, many authors anticipate a significant loss of species due to climatic change (e.g., Peters and Lovejoy, 1992; Reid, 1992; Myers, 1993; Vitousek, 1994). Due to its permanency, this must be considered as one of the most important impacts of climate change, not only in economic terms (e.g., Daily, 1995) but also in terms of all other utilitarian and spiritual values that have been attributed to species (e.g., Ehrlich and Wilson, 1991; Sharma *et al.*, 1992; Myers, 1993).

1.3.7. Adaptation

Forests themselves may to some extent acclimate or adapt to new climatic conditions, as evidenced by the ability of some species to thrive outside their natural ranges. Also, elevated CO_2 levels may enable plants to use water and nutrients more efficiently (e.g., Luo *et al.*, 1994). Nevertheless (see Sections 1.3.3 and 1.3.5), the speed and magnitude of climate change are likely to be too great to avoid some forest decline by the time of a CO_2 doubling.

Consideration may therefore be given to human actions that minimize undesirable impacts. Special attention may be given to poor dispersers, specialists, species with small populations, endemic species with a restricted range, peripheral species, those that are genetically impoverished, or those that have important ecosystem functions (Peters and Darling, 1985; Franklin, 1988; Davis and Zabinski, 1992; Franklin *et al.*, 1992). These species may be assisted for a time by providing natural migration corridors (e.g., by erecting reserves of a north–south orientation), but many may eventually require assisted migration to keep up with the speed with which their suitable habitats move with climate change. Some mature forests may be assisted by setting aside reserves at the poleward border of their range, especially if they encompass diverse altitudes, and water and nutrient regimes (Botkin and Nisbet, 1992; Peters, 1992; Myers, 1993), or by lessening pollutant stresses and land-use changes that result in forest degradation (e.g., Vitousek, 1994; Daily, 1995).

1.4. Tropical Forests

1.4.1. Characterization and Key Limitations

Tropical forests cover about 1,900 Mha (FAO, 1993a) and are found between 25°N and 25°S. They are distributed over five continents and are situated mainly in developing countries.

Box 1-5. Tropical Forests and Land-Use Changes

Tropical forests are endangered more by land-use practices than by gradual climatic change. Already at present much of the tropical forest is affected by deforestation due to land conversion and resource use (UNESCO, 1978; FAO, 1982; Brown *et al.*, 1993; Dixon *et al.*, 1994). Such anthropogenic tropical forest disturbances are expected to continue in response to economic development, population growth, and the associated need for agricultural land (DENR-ADB, 1990; Starke, 1994; Zuidema *et al.*, 1994).

Tropical rainforests have been cleared for agriculture since at least 3,000 BP in Africa and 7,000 BP in India and Papua New Guinea (Flenley, 1979). Africa has lost at least 50% of its rainforest, while tropical America and Asia have lost at least 40% (Mabberley, 1992). In addition to deforestation, large areas of previously undisturbed forest are being affected by removal of wood for timber and fuel (Brown *et al.*, 1993; Richards and Flint, 1994). Chapter 24 presents a detailed account of these deforestation trends in tropical forests.

The influence of tropical forests on local and regional climate may be as important as the effects of climate on forests (Lean and Warrilow, 1989). About 20% of the water flux to the atmosphere derives from evapotranspiration from the land, mostly from forested areas with high annual rainfall (Westall and Stumm, 1980; Lean and Warrilow, 1989). Deforestation can significantly reduce global evapotranspiration and increase runoff. This could affect the amount and distribution of precipitation over wide areas (Salati and Jose, 1984). For instance, in the Amazon basin, at least 50% of precipitation originates from evapotranspiration from within the basin (Salati *et al.*, 1979; Salati and Jose, 1984). Deforestation there will reduce evapotranspiration, which could reduce precipitation by about 20%—producing a seasonal dry period and increasing local surface temperatures by 2°C (Gash and Shuttleworth, 1991). This could result in a decline in the area of wet tropical rainforests and their permanent replacement by floristically poorer drought-deciduous or dry tropical forests or woodlands.

The forests consist of rainforests, drought-deciduous forests, and dry forests. In areas with prolonged dry seasons, especially where water limitations are intensified by edaphic conditions (Cole, 1986), there are savannas (Richards, 1966; Odum, 1971; Borota, 1991). Evergreen or partially deciduous forests occur in areas with a mean annual temperature greater than 24°C and with high regular rainfall throughout the year. Most of the closed tropical forests are found in the moist and wet zones, with precipitation to potential evapotranspiration ratios of 1–2 and greater than 2, respectively. The dry zone, with a ratio of precipitation to potential evapotranspiration of less than 1, covers about 40% of the total tropical region. In most of these forests, typical monthly temperatures fall between 24 and 28°C; daily extremes rarely exceed 38°C or fall below 10°C (Longman and Jenik, 1987).

Tropical forests represent about 40% of the world's forested area, containing about 60% of the global forest biomass and one-quarter of total soil carbon (210 Gt C in biomass and 220 Gt C in soils and litter) (FAO, 1982; Longman and Jenik, 1987; Brown *et al.*, 1993; Dixon *et al.*, 1994). Tropical forests cover only 6% of the world's surface but contain about half of all plant and animal species of the world (Bierregaard *et al.*, 1992; Mabberley, 1992; Riede, 1993). Thousands of species in tropical forests are utilized by humans. It is of particular concern that tropical forests are currently being clear-cut, burned, or otherwise degraded by human activity (see Box 1-5).

An important characteristic of tropical forests is that they maintain a tightly closed nutrient cycle and often grow on a mass of very infertile soil, in which only the uppermost few centimeters have substantial amounts of plant-available nutrients. Phosphorus is generally the main limiting nutrient (Jordan, 1985). Therefore, any disturbance that results in loss of nutrients due to leaching, erosion, or timber harvesting can result in decreased growth rates, biomass, and diversity (Whitmore, 1984; Jordan, 1985; Vitousek and Sanford, 1986).

Fire significantly influences the structure, composition, and age diversity of tropical forests. In dry forests, fires tend to be frequent, which excludes fire-sensitive species. In tropical rainforest, fire is usually rare and does not usually spread over wide areas because there is insufficient dry and flammable plant material (Chandler *et al.*, 1983a, 1983b). However, there have been instances in the past when thousands of hectares of tropical rainforest were burned following long dry periods (Goldammer and Seibert, 1990; Goldammer, 1992). Such fires are likely to significantly affect species diversity (Goldammer and Seibert, 1990) and may help prevent forest deterioration by promoting new growth and regrowth (Goldammer and Peñafiel, 1990).

Strong winds associated with tropical cyclones in tropical Asia, Central America, and northern Australia can profoundly influence the structure and floristic composition of forests (Whitmore, 1974; Hartshorn, 1978; Lugo *et al.*, 1983; Longman and Jenik, 1987; DENR-ADB, 1990; Mabberley, 1992; O'Brien *et al.*, 1992). Strong winds frequently damage tree canopies, create gaps in the forest, and modify the forest structure and micrometeorological environment. This may increase litter quality, allow more radiation to reach the forest floor, increase soil temperature, and make more soil water and nutrients available, which could promote the growth of new vegetation (Waring and Schlesinger, 1985).

1.4.2. Projected Climatic Changes

The climatic changes projected for the regions covered with tropical forest over the period 1990–2050 are increases in temperature of around 0.5–1.0°C, with no general change in seasonal amplitude; an increase in rainfall averaged over the region but with highly uncertain regional shifts in rainfall (differing greatly among GCMs), in the range -40% to +60%; and uncertain increases or decreases in soil water content (Greco *et al.*, 1994). These projections imply the potential for an increased occurrence of droughts in some regions and floods in others.

We also must consider the possibility of changes in the frequency of ENSO (El Niño Southern Oscillation; see Glossary) events, which may increase rainfall seasonality in semi-tropical regions and could lead to a longer dry season in some areas and bring more rains in other places. Fire frequencies may increase in some areas in association with drought (Rind *et al.*, 1990). Fires may further reduce local precipitation because fire-emitted aerosols increase the number of cloud condensation nuclei, producing smaller cloud droplets that are less likely to fall as rain (Andreae and Goldammer, 1992).

1.4.3. Impacts of Climate and Land-Use Changes

1.4.3.1. Forest Area, Distribution, and Productivity

All forests are expected to experience more frequent disturbance, with greater and possibly permanent impacts, such as increased soil erosion, and other forms of degradation and nutrient depletion. A study of 54 countries suggested that, between 1990 and 2050, a further 660 Mha are likely to be deforested, reducing the 1990 area by one-third and releasing 41–77 Gt C (Trexler and Haugen, 1995; see also Chapter 24). Rates of deforestation eventually must decrease as less and less of the original forest remains. There are, however, proposals to slow the loss of tropical forests (e.g., Deutscher Bundestag, 1990; UNCED, 1992), and many nations have large-scale plans for the protection or restoration of their forests (e.g., Brazil, India, and China: Winjum *et al.*, 1993).

Global vegetation models do not agree on whether climatic change (in the absence of land-use change) will increase or decrease the total area of tropical forests (depending on the calculation of transpiration and vegetation properties; see Section 1.3.4), but any major shifts in rainfall pattern due to climate and land-use change are certain to change the present distribution of vegetation types within and among biomes (Neilson, 1993). Henderson-Sellers and McGuffie (1994) show that in an enhanced-CO_2 climatic regime, tropical evergreen broadleaf forests could readily re-establish after deforestation. In some areas, decreased rainfall may accelerate the loss of dry forests to savanna, while in others, increased rainfall and increased water-use efficiency with elevated CO_2 may favor the expansion of forests and agroforestry. In both cases, the outcome will be strongly influenced by human activities. Overall, shifts in rainfall patterns in the tropics could increase the rate of conversion of forests to agricultural land by increasing human migration from areas affected by droughts, erosion, or other forms of land degradation to non-degraded and more productive forest land.

The productivities of different areas of tropical forest are likely to increase or decrease in accordance with changes in rainfall, as indicated by simulation studies (Raich *et al.*, 1991). The overall effect of predicted changes in climate (excluding elevated CO_2) on the net primary productivity of tropical evergreen forests may be a decrease due to increased temperature and consequently increased respiration (in the absence of acclimation) and decreased photosynthesis due to increased cloudiness, but elevated CO_2 levels may cause an increase in productivity (in contrast to boreal regions) unless limited by phosphorus supply (Melillo *et al.*, 1993). CO_2 enhancement of photosynthesis and growth, particularly below ground (e.g., Norby *et al.*, 1986, 1992; Luxmoore *et al.*, 1993), is favored by high temperatures in species with C_3 photosynthesis (i.e., in trees) (Long, 1991; Kirschbaum, 1994) and possibly by vegetation disturbance and consequent fast nutrient cycling (Peterson and Melillo, 1985). This is also consistent with studies of the spatial distribution of CO_2 concentrations across the globe, which also suggest that the tropics constitute a biospheric sink that partially offsets the carbon release due to deforestation (Enting and Mansbridge, 1991; Schimel *et al.*, 1995). An alternative view is that elevated CO_2 levels will accelerate carbon and nutrient cycles in tropical ecosystems without increasing growth and biomass (Körner and Arnone, 1992). Researchers are agreed, however, that increased water-use efficiency by plants in response to elevated CO_2 is likely to enhance the productivity of vegetation in the drier tropical regions.

Land-use change is obviously the greatest threat to species diversity of tropical forests, but Cramer and Leemans (1993) speculate that climatic change alone could decrease the diversity of plant types at the boundaries of biomes, particularly in the tropics. Losses are likely to be greatest where the pressures of population and socioeconomic forces are greatest and least controlled (see also Section 1.3.6).

1.4.3.2. Temperature

In general, temperatures in non-montane tropical regions are already high enough for rapid growth year round, and a 2°–3°C increase in temperature alone will have a marginal effect on rates of photosynthesis, growth, decomposition, and nutrient cycling. However, if plants experience temperatures above 35°–40°C over extended periods, especially in combination with water shortage, tissue damage from desiccation and sunscald can occur (Fitter and Hay, 1987). In drier areas, the severity and duration of dry spells could be aggravated by increasing temperature. Also, some species sustain damage from temperatures below 10°–12°C or even below 15°–20°C, and there may be some limited future expansion of those species into regions from which they are currently excluded by cool temperatures (e.g., Smith *et al.*, 1992b).

1.4.3.3. Water

In the semi-arid tropical regions, climate-induced desertification will be a critical issue if precipitation decreases (Mitchell *et al.*, 1990; Greco *et al.*, 1994). Seasonally dry deciduous forests could burn more frequently and be permanently replaced with thorn scrub or savannah vegetation. It should be noted that changes in forest cover can have effects on groundwater supplies, surface runoff, sedimentation, and river flows (Brooks *et al.*, 1991), with potentially serious socioeconomic effects (see also Chapter 5). Also, hydrological changes that include shifts in atmospheric circulation could threaten the survival of cloud forests.

Some evergreen species of the humid forest clearly will be at a disadvantage in those areas that experience more severe and prolonged droughts. Significantly, drought affects the survival of individuals: Those without morphological or physiological adaptations to drought often die. In contrast, an abundance of moisture (in the absence of flooding) more often acts through changed competitive ability. Drought-adapted species are outcompeted by those that lack growth-limiting drought-adaptive traits. Species in moist tropical forests, including economically important hardwoods, are the least drought-adapted in the tropics, and their survival (with the attendant loss in diversity) in some areas must be considered at risk from climatic change.

1.4.3.4. Soil Nutrients

Climatic change (including elevated CO_2 levels) could enhance the supply of nutrients to plants in the tropics by, for instance, increasing root and mycorrhizal growth and thereby increasing access to soil phosphorus and enhancing nitrogen fixation by legumes, which are abundant in the tropics. On the other hand, the more important considerations are likely to be nutrient leaching and soil erosion wherever tree cover is lost (because of droughts or fire) or removed (by logging, clearing, or grazing)—especially where high-rainfall events occur in hilly areas—and immobilization of nutrients in soil organic matter in response to elevated CO_2.

1.4.3.5. Pests and Pathogens

Tropical rainforests contain large numbers of insects and pathogens that can cause serious damage to some plant species and may play a role in regulating species diversity (Coley, 1983). Many factors have been associated with the susceptibility of tropical plants to pests and diseases and with the virility of pests and pathogens. Some of these factors include suboptimal climate, availability of water and nutrients, and the presence of secondary metabolites that act as defensive compounds (Lambert and Turner, 1977; Levitt, 1980a, 1980b; Mattson, 1980; Mattson and Haack, 1987; Jones and Coleman, 1991). Drought stress can sometimes increase host plant suitability due to increases in soluble nitrogen and sucrose (White, 1974), whereas high temperatures and humidities (> 30°C and relative humidity of 50–90%) can decrease the growth rate, survival, and fecundity of some insects (Wilson *et al.*, 1982). Consequently, there is still great uncertainty as to whether the impacts of climate change on the relationship between host plants and pests and pathogens will lead to forest loss or gain.

However, the diversity of species in most tropical forests appears to confer some protection against widespread outbreaks of pests and diseases. The low population density of potential hosts prevents the rapid multiplication and spread of pests and pathogens (Longman and Jenik, 1987). Hence, most cases of debilitating outbreaks of pests and diseases—which can, for instance, affect entire stocks of some mahoganies—occur in plantations, agroforests, or stands that are dominated by one species (UNESCO, 1978).

1.4.3.6. Fire and Wind

It is clear from recent events that wherever there are more droughts, there will be more fires due to the accumulation of more combustible dry organic matter, with major potential economic costs in highly populated areas. In the extreme, recurrent fires will lead to the permanent loss of fire-prone species and the invasion and maintenance of fire-resistant species such as savanna vegetation. Fires, together with the action of wind—especially in regions where storms are frequent—will increase the dominance of pioneer species, including vines and herbs, preventing forests from developing to maturity.

1.5. Temperate Forests

1.5.1. Characterization

Temperate forests occur approximately from 25–50° N and S and are found primarily in developed countries in discontinuous blocks on five continents, sharing the landscape with agricultural land and urban areas. Closed forests originally covered about 1,400 Mha but have been reduced to about 700 Mha, 56% of which is in North America and 24% in Europe (see Chapter 15). Humans have had an impact on almost all of these forests; about 20% are managed for wood production or other uses, and many are being affected by pollutants, with both potentially positive and some obvious negative effects on growth (Innes, 1993).

These forests contain broadleaved and needle-leaved species that may be evergreen or deciduous. The most extensive types of temperate forests are the northern deciduous forests, commonly dominated by members of the *Fagaceae*, with leaf-shedding as an adaptation to winter frosts; the temperate coniferous forests of Europe, western and southeastern North America, and eastern Asia; warm evergreen forests in Australia dominated by *Eucalyptus* species; and other forests in the Southern Hemisphere dominated by *Nothofagus* species.

Temperate forests occur within a range of mean annual temperatures of 6–17°C, where average total precipitation exceeds 500 mm, with broad transition zones to boreal and subtropical forests. Within any region there are often steep gradients in forest types along climate gradients of rainfall and temperature, with change in altitude, and from oceanic to continental areas. At the low-rainfall margin, temperate forests change into savanna-type woodlands or Mediterranean shrublands. Temperate forests exist on a wide range of soils and have diverse ecological properties (Ellenberg, 1971; Bormann and Likens, 1979; Reichle, 1981; Edmonds, 1982).

The standing biomass and carbon content of temperate forests is currently increasing (at 0.2–0.5 Gt C yr^{-1}), largely due to reforestation (about 0.6 Mha yr^{-1}), underharvesting and regrowth after wood removal during the 19th and early 20th centuries (Armentano and Ralston, 1980; Heath *et al.*, 1993; Kurz and Apps, 1993; Sedjo, 1993; Sundquist, 1993; Dixon *et al.*, 1994; Galinski and Küppers, 1994; Kohlmaier *et al.*, 1995), and mainly fertilization effects of nitrogen deposition (Kauppi *et al.*, 1992). The temperate forests therefore are considered to be a carbon sink (Heath *et al.*, 1993). However, if the loss of carbon from decaying forest products and logging debris is taken into account, the net flux of carbon to the atmosphere from northern temperate forests is close to zero (Houghton, 1993) and, in the coming century, increased demand for wood may change the temperate forests to a net carbon source (Heath *et al.*, 1993).

Forest fires occur in most seasonally dry forests, despite control measures, and play an important role in ecosystem dynamics in these forests, especially in parts of North America, Australia, and Mediterranean Europe (Kozlowski and Ahlgren, 1974; Gill *et al.*, 1981; Goldammer and Jenkins, 1990). Fire affects species distribution by favoring fire-resistant species at the expense of those more sensitive to fire. Fire also creates conditions conducive to the establishment of new seedlings.

1.5.2. Key Limitations

The ranges and growth of temperate tree species in wetter, maritime, and high-latitude regions often can be related to the length of the growing season, measured in degree-days, and to absolute minimum temperatures in more continental areas. The temperature niches of individual species are often narrow (Figure 1-1) and are commonly determined by critical thermal requirements of the reproductive cycle (e.g., Pigott and Huntley, 1981).

In drier regions closer to the equator, the existence and growth of temperate forests are controlled largely by water availability. Variation in leaf-area indices and ring widths often is related to available water (Gholz, 1982). A minimum ratio of actual to potential evapotranspiration of approximately 0.65 is considered necessary to support the growth and regeneration of temperate-zone trees (Prentice *et al.*, 1992). Slight shifts to smaller ratios lead to open woodlands, savannahs, and grasslands. Soil water availability also strongly influences forest density, leaf area, growth, and standing biomass.

Seedling establishment is most vulnerable to shifts in precipitation patterns or amounts. Most temperate-zone seedlings can survive and become established only within narrow limits of soil moisture and sunlight. Slight changes in soil moisture can lead to the loss of a season's seedling crop, although losses in tree establishment cohorts may not lead to changes in forest structure for decades.

Like high-latitude populations experiencing low temperature, mid-latitude populations that are often subject to low soil water availability may be very plastic in their response to environmental variation. This plasticity enables temperate-zone trees to survive most weather variations that may be encountered only once every 200 years (Bugmann, 1994). Reproduction at these locations may be possible if conditions in rare years are favorable for the species' reproductive requirements (Pigott and Huntley, 1981).

1.5.3. Projected Climatic Changes

The climatic changes projected for most of the temperate forest region over the period 1990–2050 are increases in both summer and winter temperatures of 1–2°C; regional changes in precipitation in summer and winter, mostly in the ±20% range; and drier soils in summer (mostly with 2–8 mm less water) and, in winter, changes toward drier soils in some regions and wetter soils in others (Greco *et al.*, 1994). These projections imply longer and warmer growing seasons, less extreme subzero temperatures in winter, more frost-free winters in maritime areas, and more summer droughts, particularly in mid-continental regions (Manabe and Weatherald, 1987).

Possibly more important to temperate biotic communities than the magnitude of warming or precipitation change is the speed of climatic change (see Section 1.3.5). The projections imply that it will take less than a century for the summers to be warmer than now throughout the current geographic range of many temperate species.

1.5.4. Impacts of Climatic Change

1.5.4.1. Forest Area, Distribution, and Productivity

As long as the current agricultural surpluses in temperate regions persist, the temperate forest area is likely to be increased by afforestation. In Europe, the potential area for afforestation has been estimated as 44 Mha, and in the United States 100 Mha (Heath *et al.*, 1993).

Climatic change will enable the temperate forest to advance poleward, in many northern areas displacing boreal forest, and also potentially to expand in wet, maritime regions (Kellomäki and Kolström, 1992; Leemans, 1992; Morikawa, 1993). Early successional, pioneer species will be favored, and opportunities will exist for foresters to introduce species and ecotypes from warmer regions (Cannell *et al.*, 1989). However, in drier, continental regions, repeated summer droughts may lead to the loss of temperate forests. The rate of loss in biomass and carbon in these areas could exceed the rate of carbon gain in newly forested areas (Smith *et al.*, 1992a).

The net primary productivity of temperate ecosystems is predicted to increase in response to rising CO_2 concentrations, warming, and increased nitrogen mineralization rates; however, if drier areas, such as those west of the Appalachians, receive just 7% less rainfall, decreased productivity is predicted because of a decrease in the ratio of rainfall to potential evapotranspiration (Running and Nemani, 1991; Melillo *et al.*, 1993; Lüdeke *et al.*, 1995). Similarly, warming of 2°C and slightly decreased precipitation have been predicted to cause forest decline in Missouri (Bowes and Sedjo, 1993). Many experiments have confirmed that elevated CO_2 enhances the growth of young trees and that the effect is sustained over several years (Wullschleger *et al.*, 1995). However, it has proven difficult to detect CO_2-enhanced stem growth of mature trees over the last century (see Section 1.3.1.2 and Chapter A).

Forests that are not in decline may show little change in net carbon storage because, in temperate climates, increases in net primary productivity may be offset by increased soil respiration due to higher temperatures (Thornley *et al.*, 1991; Kirschbaum, 1993). That is, the net ecosystem productivity may not change, and may even decrease. Forests suffering from wildfire, pest outbreaks, or decline events will lose carbon and may become a major source of carbon (King and Neilson, 1992; Smith and Shugart, 1993).

1.5.4.2. Temperature and Water

Species in the temperate zone differ in their temperature optima for growth, their timing and degree of frost hardening and dehardening, their winter chilling requirements, and the number of degree-days needed to complete different stages in their reproductive development (Cannell, 1990). All of these differences are likely to be involved in driving changes in the distribution and productivities of species. Most studies predict substantial change during the next century, but confidence in our predictions is limited by knowledge of adaptive responses of species and the need to consider interactions among responses to temperature, CO_2, changed water relations, and pests and pathogens. Moderate temperature increases alone often can be beneficial, as evidenced by the faster growth and greater seed production of some commercial tree species when transferred to slightly warmer climates. But chilling requirements may not be met, and delayed budburst may limit the amount of light intercepted in the growing season while total respiration increases (LeBlanc and Foster, 1992). It also has been shown that frost hardiness can decrease in response to CO_2 enrichment (Barnes *et al.*, 1996), so that winter damage could even increase.

Species that are growing in regions where growth is limited by water shortages for at least part of the year may be adversely affected by intensification of summer soil water deficits (Greco *et al.*, 1994), as a result of decreases in the ratio of rainfall to potential evapotranspiration (e.g., Addison, 1991).

Warm winters will result in less precipitation falling as snow and reduced regional snow packs, resulting in less carry-over of water from the winter to the growing season (Mitchell *et al.*, 1990). Thus, less water will be available for vegetation in the following growing season, which may lead to drought-induced forest decline (King and Neilson, 1992).

1.5.4.3. Pests and Pathogens

Warming in winter may allow destructive insects and pathogenic fungi to survive at higher latitudes than at present, enabling subtropical or warm-temperate pests and pathogens to invade vegetation from which they are now excluded (Dobson and Carper, 1992). Some insects also will be able to complete more generations per year in warmer climates. Increased incidences of pests and diseases may further limit the growth of stands that are already declining from the effects of climate change or pollution. Summer droughts and other climatic stresses have been associated with outbreaks of bark beetles like the southern pine beetle (*Dendroctonus frontalis*) in southern parts of the United States, bark beetles in western Canada (Kimmins and Lavender, 1992), and bronze birch borers on paper birch in northern Michigan (Jones *et al.*, 1993). Elevated CO_2 can change the palatability of leaves and either promote or discourage insect herbivory (Overdieck *et al.*, 1988; Mueller-Dombois, 1992). In areas where forestry practice has led to the establishment of mono-specific stands, forests are particularly vulnerable to outbreaks of pests and diseases, especially where that combines with poor site quality or exposure to industrial pollutants.

1.5.4.4. Soil Nutrients

Nitrogen supply generally limits the productivity of many temperate forests (Tamm, 1991). Climatic warming will increase rates of turnover of soil nitrogen and carbon. In Europe and the United States, nitrogen fertility also may be improving through inputs from industrial and agricultural pollution. While a low level of nitrogen input may have a beneficial effect (Kauppi *et al.*, 1992), further inputs could reverse the initial gains through the development of nutrient imbalances and further acidification of the soil (Heath *et al.*, 1993).

1.5.4.5. Fire

The projected increase in the incidence of summer droughts in much of the temperate zone will increase the risk of forest fires and extend the hazard to areas that are not now affected, particularly where forests are defoliated or killed by drought, pests, or pathogens. Some species that are not adapted to withstand or regenerate after fire may be lost from fire-affected areas. However, large-scale fires may continue to be rare in the temperate zone and confined to drier parts of North America, Australia, and the Mediterranean region because temperate forests mostly occur in dissected landscapes in countries that can afford fire-control measures.

1.6. Boreal Forests

1.6.1. Characterization

The boreal forest covers approximately 17% of the world's land surface area in a circumpolar complex of forested and partially forested ecosystems in northern Eurasia and North America. It contains about 90 Gt C in living biomass and 470 Gt C in soils and detritus (Dixon *et al.*, 1994); the boreal region is estimated currently to be a sink of 0.4–0.6 Gt C yr^{-1} (Apps *et al.*, 1993; Dixon *et al.*, 1994).

The boreal forest consists primarily of evergreen and deciduous coniferous species and is floristically poor, being dominated by only about 15 tree species in both Eurasia and North America (Nikolov and Helmisaari, 1992). Many species have transcontinental distributions and are adapted to withstand extremes of climate and to regenerate after fire or insect attack. Three forest zones are often recognized (from south to north): closed-crown forest, open-crown forest (or lichen woodland), and forest-tundra. The closed-crown forest borders on steppe/prairie in continental areas, whereas in areas under maritime influence the boreal/temperate forest boundary consists of a relatively species-rich community—often in a mosaic of deciduous species on favorable soils and conifers at less favorable or colder sites (Apps *et al.*, 1993). Much of the boreal forest is embedded in a mosaic of wetlands and peatlands that may act as natural fire breaks. Mosses and lichens also play an important role in boreal ecosystem processes.

The northern limit of the boreal forest is largely determined by temperature (Garfinkel and Brubaker, 1980; Larsen, 1980, 1989; Arno, 1984), while both temperature and water supply determine the forest/steppe and forest/prairie boundaries. In general, the length of the vegetative period (related to the length of the frost-free period or July mean temperature) is of great importance in maritime regions. In more continental regions, drought or extreme subzero temperature may be more important—for instance, the apparent -40°C limit of sap supercooling of hardwood species (Arris and Eagleson, 1989) and the winter or drought tolerance of evergreen conifers. This tolerance may be exceeded in Siberia, which supports large areas of deciduous conifers (*Larix*) (Woodward, 1987). Drought is an important factor in interior Alaska and Siberia, where annual precipitation may be as low as 100–200 mm. Throughout the boreal region, droughts are generally necessary for the onset of fires. Some species, notably *Pinus sylvestris*, are drought-tolerant, whereas others such as *Picea abies* are dominant on wetter soils. A further factor determining the limits of species may be their winter chilling requirements.

The boreal forest consists of a patchwork of small to very large areas that are in various stages of recovery from fire or insect attack (van Cleve *et al.*, 1983a). Stands rarely reach maximum biomass or carbon content (Apps and Kurz, 1994), and many areas are dominated by one or a few species in a narrow age-class range. Also, it may be noted that the boreal forest is less than 12,000 years old and still may be expanding in some areas (Tallis, 1990), and even recovering from cool temperatures in the Little Ice Age (AD 1200–1850) (Campbell and McAndrews, 1993).

1.6.2. Key Limitations

Low air temperatures and small heat sums restrict growth and the production and germination of seed, which is a major factor limiting regeneration in the forest-tundra zone (Henttonen *et al.*, 1986). Unseasonal frosts can damage growth and reproductive cycles. Low soil temperature and permafrosts (in non-oceanic regions) have been demonstrated experimentally to limit growth and nutrient availability (van Cleve *et al.*, 1981, 1983b). Permafrost can restrict root growth and create an impervious layer that impedes soil drainage but can also be responsible for raised areas that permit drainage, producing islands where trees can grow within wetlands.

Low nutrient availability (except after fire) is characteristic of most boreal forests. Low soil temperatures limit the rate of litter decomposition and mineralization (Shaver *et al.*, 1992; Berg *et al.*, 1993; Kobak and Kondrasheva, 1993), and the litter of most coniferous boreal tree species is relatively resistant to decomposition because of its high lignin and low nutrient content. Nitrogen availability in boreal coniferous forests is generally in the range of 5–40 kg N ha^{-1} yr^{-1}, compared to 80–120 kg N ha^{-1} yr^{-1} in northern hardwood stands (Pastor and Mladenoff, 1992).

Natural wildfires are ubiquitous throughout the boreal region because of the buildup of large amounts of litter, much of which is not only resistant to decomposition but is also highly flammable. In the absence of fire-suppression measures, the interval between fires (the fire cycle) ranges from 50 to 200 years from south to north but may be over 1,000 years in wet northern ecosystems (Viereck, 1983; Payette *et al.*, 1989b; Payette, 1992). There are well-established relationships between fire-cycle length, species composition, age-class distribution, and carbon storage (Johnson and Larson, 1991; Kasischke *et al.*, 1995; Kurz *et al.*, 1995).

Boreal forests also are characterized by periodic outbreaks of insect pest populations. For many insect species, outbreaks have been clearly associated with climatic conditions and weather events (e.g., Martinat, 1987; Mattson and Haack, 1987; Volney, 1988), and outbreaks are often most common in the southernmost (warmest) part of the tree-host range (Kurz *et al.*, 1995). On sites where forests have remained unaffected by fire or insect damage for extended periods, they are characterized by multi-aged stands where tree-fall constitutes the most important disturbance. Tree falls create a variety of microenvironments that enhance diversity and affect regeneration patterns (Jonsson and Esseen, 1990; Liu and Hytteborn, 1991; Hofgaard, 1993).

The net primary productivity of boreal forests tends to be low—commonly 3–8 t (dry matter) ha^{-1} yr^{-1}, compared with 7–12 t ha^{-1} yr^{-1} for northern hardwoods (Cannell, 1982; Melillo *et al.*, 1993). Productivity is controlled in a complex way by interactions between various factors as discussed in Section 1.6.4 (Bonan and Shugart, 1989). As a boreal forest stand develops after fire, litter accumulates, more and more nutrients are immobilized in the litter, the depth of thaw is reduced because of the insulating properties of the litter, drainage may then be impaired by permafrost, and moss growth may impair regeneration from seed—some of which may be held within serotinous cones that release their seed only after fire (Bonan, 1992). Fire interrupts this process by burning litter on the forest floor, releasing mineral nutrients, leading to deeper thaw, improving drainage, and often removing the moss layer—all of which improves conditions for seed germination (Landhäusser and Wein, 1993).

1.6.3. Projected Climatic Changes

The climatic changes projected for most of the boreal region over the period 1900–2050 are increases in temperature of around 1–2°C in summer and 2–3°C in winter; regional changes in precipitation in summer and winter, mostly in the ±20% range; and drier soils in summer (averaging about 2–8 mm less water) (Greco *et al.*, 1994). These projections imply longer and warmer growing seasons, appreciably milder winters with the possibility of less extreme minimum temperatures, and less permafrost, which is related to annual mean temperatures.

Most importantly, the changes in temperature, soil water, and vapor pressure deficit may increase the frequency (shorten the return-time) of fires. Flannigan and van Wagner (1991) predict a 40–50% increase in the area burned each year in Canada in a 2 x CO_2 climate scenario, and others have predicted more frequent fires of higher intensity in the forest-tundra (Stocks, 1993; FIRESCAN Science Team, 1995). In Russia, an additional 7–12 million hectares of boreal forest are projected to burn annually within the next 50 years, affecting 30–50% of the land area (Dixon and Krankina, 1993).

1.6.4. Impacts of Climatic Change

There is a general consensus that climatic change will have greater impact on boreal forests than on tropical and perhaps temperate forests, and that more frequent or changed patterns of disturbance by fire and insect pests may be more important agents of change than elevated temperatures and CO_2 levels *per se* (Shugart *et al.*, 1992; Dixon and Krankina, 1993). Overall, the boreal forest is likely to decrease in area, biomass, and carbon stock, with a move toward younger age-classes and considerable disruption at its southern boundary (Neilson *et al.*, 1994; Kurz *et al.*, 1995). CO_2 enrichment itself may have less effect than in warmer climates. In Sections 1.6.4.1 through 1.6.4.4, we consider the likely changes in the distribution and composition of the forest and then elaborate on the factors driving change.

1.6.4.1. *Forest Area, Distribution, and Productivity*

On its southern border, the boreal forest may give way to northern deciduous forest (or agriculture) in areas with a maritime influence and to grassland or xerophytic steppe vegetation in midcontinental areas, and species shifts may occur in the mid-boreal region (Emanuel *et al.*, 1985; Kellomäki and Kolstrom, 1992; Rizzo and Wiken, 1992; Dixon and Krankina, 1993; Monserud *et al.*, 1993a; Tchebakova *et al.*, 1994; Prentice and Sykes, 1995). Near tree lines in many areas, there is potential for existing populations of suppressed individuals to grow taller and more vigorously, as has apparently happened in response to past climatic changes (Kullman, 1986; Payette *et al.*, 1989a; Hofgaard *et al.*, 1991).

Over the next century, the potential (or preferred) geographic ranges of species may shift approximately 300–500 km, implying changes in forest-based industries and considerable socioeconomic impacts. In the early Holocene (about 8,000 years ago), when the climate became warmer, fire-adapted hardwood species expanded northward to new sites after fire (Green, 1987). Where northern deciduous species, such as sugar maple, migrate northward, forest productivity may be increased on soils that retain adequate water, whereas productivity may decrease on dry soils where boreal forest may give way to oak-pine savanna (Pastor and Post, 1988).

There is concern that the maximum potential migration rates may be too slow to keep up with the rate of climatic change (see Sections 1.3.3 and 1.3.5)—in which case some researchers consider that there may be areas of transitory forest decline, especially if soils change slowly, are unfavorable for immigrating species, and lack necessary microbes and symbionts (Dixon and Turner, 1991; Davis and Zabinski, 1992; Solomon, 1992; Smith and Shugart, 1993), or where growth by more southern species is limited by photoperiodic constraints. The future of the transitory forest is likely to be determined by increasing occurrence of extended high-intensity wildfires until a new climate-vegetation-fire equilibrium is established (Crutzen and Goldammer, 1993). Other researchers suggest that there may be little forest decline. Intraspecific genetic diversity will buffer change, and species that are no longer in a favorable climate will simply grow and regenerate poorly and be overtaken by invading species either gradually or after disturbance (Malanson *et al.*, 1992; see also Section 1.3.3).

Increasing temperatures are likely to stimulate soil organic matter decomposition and increase nutrient (especially nitrogen) availability, leading to an increase in net primary productivity of non-stressed stands, averaging perhaps 10% in the boreal zone in a 2 x CO_2 climate (Melillo *et al.*, 1993). However, despite increasing productivity, there may be a net carbon loss from the ecosystem because a small temperature rise will greatly enhance decomposition rates (Jenkinson *et al.*, 1991), whereas CO_2 fertilization will be of low effectiveness because of low temperatures (Kirschbaum, 1993). Also, productivity may not increase in dry areas if water limitations were to increase due to increased evaporative demand. Hydrological and landscape changes in the patterns of bogs and forest also may be expected. In the north, melting of permafrost would favor the expansion of wetlands, while drier conditions in the south would lower the water tables (Apps *et al.*, 1993).

In the forest-tundra, rising temperatures are likely to enhance the development and germination of seeds of many species, increasing forest cover and enabling a northward migration to occur, probably after fire (Kullman, 1990; Kellomäki and Kolström, 1992; Landhäusser and Wein, 1993)—but again, hampered to some extent by slow changes in soil conditions (Rizzo and Wiken, 1992). There is clear evidence in the fossil pollen and macrofossil record of expansion and recession of boreal forest in both Eurasia and North America in response to temperature changes over the past 10,000 years (Ritchie, 1987). However, it will take more than 100 years for any new forest areas to mature in the forest-tundra, so the northward expansion of mature boreal forest is likely to be slower than the rate at which it is lost to grassland and temperate deciduous forest at its southern boundary (Rizzo and Wiken, 1992). The tundra itself is likely to become a carbon source in response to warming (Billings *et al.*, 1984; Oechel *et al.*, 1993).

1.6.4.2. *Temperature*

The productivity of boreal forests—except those at the warmer and drier edge of their species ranges—is likely to respond favorably to increases in temperature, as shown by long-term soil warming experiments and models (van Cleve *et al.*, 1990; Melillo *et al.*, 1993). It has long been known that trees in the boreal forest exhibit positive relationships between annual growth-ring widths and summer temperatures (Mikola, 1962) and between volume growth and number of degree-days (Kauppi and Posch, 1985; Worrell, 1987). Also, most provenance-transfer studies suggest that some southward movement of ecotypes to warmer climates promotes their volume growth (Beuker, 1994; Matyas, 1994). The magnitude of the growth response will depend on the effect of increased temperatures on nutrient availability, evapotranspiration, and the frequency of fires. Subtle interactions may be important. For instance, Bonan *et al.* (1990) and Bonan (1992) show how increased temperatures combined with increased evapotranspiration could result in a faster build-up of litter and a shallower permafrost zone, but an increased probability of fire. The net effect could be to reduce nutrient availability except after fires—whereas on the basis of temperature increases alone, nutrient availability would have been expected to increase (Shaver *et al.*, 1992).

Forest simulation models suggest large shifts in species composition in boreal forests (Shugart *et al.*, 1992). Large increases in temperature would cause annual heat sums to exceed the minimum thresholds for seed production, favoring the northward spread of species, especially in the forest-tundra zone. On the other hand, reduced winter chilling may disrupt both vegetative growth and reproductive processes of species at the southern edges of their ranges (Kimmins and Lavender, 1992).

1.6.4.3. Nutrients

Nitrogen is the nutrient that most limits the productivity of boreal forests (e.g., van Cleve *et al.*, 1983a, 1983b; Tamm, 1991). The critical factor is the rate at which nitrogen is recycled through the litter—which, as noted earlier, is a function of both temperature and litter quality (Berg *et al.*, 1993). Species differ in both their response to nitrogen and their litter quality. *Picea* sites in cold locations have forest floors with a high lignin content, little available nitrogen, and slow decomposition rates, whereas *Betula* or *Populus* sites, especially in warmer locations, have forest floors with less lignin. Thus, whereas small increases in temperature will increase rates of decomposition and nitrogen cycling, large or prolonged temperature increases also will lead to a shift from coniferous to deciduous tree species, and—because of the greater decomposability of deciduous litter—this may have a further positive effect on nitrogen availability, leading to increased productivity. On the other hand, increasing CO_2 concentration could increase the C:N ratio of litter, and the reduced litter quality might slow the rate of nutrient cycling (Taylor *et al.*, 1989; van de Geijn and van Veen, 1993).

1.6.4.4. Fire and Insects

In Canada over recent years, about 1 to 2 Mha have burned each year (Kurz and Apps, 1993), and in Russia, between 1.4 and 10 Mha burned each year between 1971 and 1991 (Dixon and Krankina, 1993). If fires occur very frequently, late successional species become unable to outcompete pioneer species, which will thereby become more common. A threefold increase in wildfire frequency in Canada between a high-fire year (1989) and a reference year (1986) resulted in an 86% reduction in the net ecosystem carbon sink (Kurz *et al.*, 1992). However, fires also have a beneficial effect on subsequent ecosystem function and facilitate regeneration (Landhäusser and Wein, 1993). Fires may have most impact in the forest-tundra zone; indeed, Payette and Gagnon (1985) conclude that the modern forest-tundra boundary of northeastern North America is the result of fires during the last 3,000 years, which were followed by lower temperatures that limited forest regeneration. If future fires were followed by higher temperatures, the fires could be catalysts for a return to coniferous forests that appear to have existed there 7,000–10,000 years ago.

Defoliating insects play an important role in boreal forests, and there are many instances where the proportion of different boreal tree species is related to the intensity of insect pest outbreaks. Pests usually are maintained at a low population equilibrium by a combination of host resistance, natural enemies, and weather conditions. Any one of these factors could be affected by climatic change, particularly tree resistance in response to environmental stress. Once an outbreak exceeds a certain patch size, it can become self-propagating and can spread largely independently of weather conditions. Following climatic warming, it seems very likely that insect outbreaks will expand northward and that new pest and pathogen problems will arise (Kurz and Apps, 1993).

1.7. Research and Monitoring Needs

Our capability to assess the likely fate of the world's forests under altered climatic conditions has been limited because the conceptual modeling framework for such an assessment is still in an early stage of development. It needs to be refined to improve the understanding of climate change impacts at the following three levels: (1) the ecophysiological responses of trees to changing climate and CO_2 concentrations, (2) the relationship between tree growth and transient forest dynamics, and (3) the influence of changing forest characteristics on the global carbon balance and hence their feedback to the greenhouse effect. The predictive power of current modeling approaches decreases from (1) to (3). A consistent research strategy to overcome these limitations needs to be accompanied by a monitoring program that can provide appropriate databases for initialization, calibration, validation, and application of the models. In particular, future work should address the following:

- *Ecophysiology*, specifically the influence of temperature, water availability, ambient CO_2 concentration, photoperiod, and nitrogen availability on the establishment, growth, water use efficiency, stomatal conductance, biomass allocation, and survival of trees under natural conditions. Urgently required also are studies of belowground plant and soil processes such as the decomposition of organic residues under changing environmental conditions. Most previous studies have been limited to short-term responses of young trees and therefore have ignored longer-term processes influenced by more than one factor, as well as the adaptive potential of plants. There is a need for more long-term studies that investigate simultaneously a well-defined set of key factors. The ecophysiological responses should be measured at experimental sites within a range of forest types, and those experiments should follow protocols that support modeling research.
- *Forest dynamics*. Studies should focus on the stability of natural and managed forests under different types of climatic (temperature, water availability) and

chemical (CO_2, nitrogen) regimes, including the influence of changing disturbance conditions (wind, drought, fire, pest frequencies). Because the direction and magnitude of possible climatic change is not known for all factors relevant to ecosystem dynamics, simulations and experimental studies should focus upon a broad range of such conditions. The potential rate of species migration (either assisted or unassisted) needs to be investigated further using appropriate models. A significant part of this activity should be devoted to further development of monitoring strategies that would allow the collection of data on realistic forest responses through all major forest regions.

- *Monitoring*. The development and application of forest models requires improved global databases on the present conditions of the world's forests, as well as their associated site characteristics. It is crucial that these data-gathering activities are intensified, both through the global network of ground observations that can be made in many research institutes worldwide and through the collection of data from spaceborne sensors. For ground-based data collection, standardization and worldwide availability are key issues, as is the continuation of already ongoing observational series. Satellite remote sensing is in a promising stage of development, with respect to both enhanced processing protocols of existing time series of satellite data (such as AVHRR) and the development of sensors with improved capacity to measure ecosystem properties at high spatial and temporal resolution.

To improve the overall modeling framework for the assessment of global forest response to climate change, and to provide an appropriate background for the synthesis of more detailed studies, there is a requirement for process-based terrestrial biosphere models of ecosystem dynamics. These models should build on knowledge from all other levels of model development. Specifically, they should involve a sufficiently high number of plant functional types and forest types to cover the wide range of forests occurring in different climate zones. Various initiatives for the development of such models are currently underway (e.g., Focus 2: Change in Ecosystem Structure, especially activity 2.3. in Steffen *et al.*, 1992; Landsberg *et al.*, 1995). To succeed, they need to be backed up by the research activities listed above.

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Climate Change 1995

Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses

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<u>Impacts on Other Natural Areas</u>

Q27. On page 15 of your written testimony you state the following:

"Other Natural Areas: Natural ecosystems are highly vulnerable to degradation from climate change. Federally protected natural areas have become a repository for the Nation's rarest species and are critical for the conservation of biological diversity. The composition, geographic distribution, and productivity of many ecosystems will shift as individual species respond to changes in climate. These will likely lead to reduction in biological diversity and in the goods and services ecosystems provide for society, such as clean water and recreation. Freshwater wetlands are particularly at risk from climate change. IPCC findings show that:

- **Precipitation changes and salt water intrusion from sea level rise could adversely affect the ecological communities of the Florida Everglades and degrade the habitat for many species of wading birds.**

- **The wetlands of the prairie pothole region of North America, which support half the waterfowl population of this continent, could diminish in area and change dramatically in character in response to climate change, significantly exacerbating the destruction already caused by agriculture."**

Please document these statements.

A27. Two chapters of the document *Climate Change 1995 – Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses* summarize the IPCC's most recent findings on impacts on and adaptations for non-tidal wetlands (Chapter 6) and coastal zones and small islands (Chapter 9) in a changing climate. Copies of these chapters are attached.

6

Non-Tidal Wetlands

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CONTENTS

EXECUTIVE SUMMARY

Although there are many different systems for defining and classifying wetlands, for this chapter we define wetlands generally as areas of land where the water table is at or near the surface for some defined period of time, leading to unique physiochemical and biological processes and conditions characteristic of waterlogged systems. Wetlands exist in both inland and coastal areas, covering approximately 4–6% of the Earth's land surface. They are found on every continent except Antarctica and in every climate from the tropics to the tundra. This chapter examines the possible impacts of climate change on non-tidal (primarily inland) freshwater wetlands.

Wetlands have many functions that have socioeconomic benefits: They provide refuge and breeding ground for many species, including commercially valuable ones; they are areas of high biodiversity; they control floods and droughts and improve water quality; and they are used for recreation and education. The direct economic value of these benefits varies between regions.

Human activities—such as the conversion of wetlands to agricultural and forest lands, construction of dams and embankments, and peat mining—already pose a serious threat to wetlands worldwide. Mainly as a result of these activities, it is estimated that more than half of the world's wetlands have disappeared during the last century. These anthropogenic effects are most notable in densely populated areas and are expected to increase, especially in developing countries.

We are highly confident that climate change will have its greatest effect on wetlands by altering their hydrologic regimes. Any alterations of these regimes will influence biological, biogeochemical, and hydrological functions in wetland ecosystems, thereby affecting the socioeconomic benefits of wetlands that are valued by humans. Due to the heterogeneity of non-tidal wetlands, and because their hydrologic conditions vary greatly within and among different wetland types and sites, the impacts of climate change on these ecosystems will be site-specific. Impacts can be generalized for specific wetland types and, to some degree, wetland regions. However, generalization across wetland types is difficult and cannot be made in terms of locations or wetland categories.

We are highly confident that hydrologic changes or other disturbances that change the vegetation types in wetland areas will affect other wetland functions as well. However, many wetlands have inherently high spatial and temporal variability in plant communities due to climatic variations (e.g., seasonal flooding or drought) and variations in microtopography. We are confident that in some wetlands a changed plant community as a result of climate change will resemble at least some component of the existing community.

We are highly confident that climate change will affect the cycling of carbon in wetlands: Some carbon-sequestering wetlands will change from CO_2 sinks to sources due to a lowering of the water table or increased temperature. Changes in the source/sink relationship of wetlands have already occurred in parts of the arctic region. Climate change leading to an alteration in the degree of saturation and flooding of wetlands would affect both the magnitude and the timing of CH_4 emissions. Drying of northern wetlands could lead to declines in CH_4 emissions.

We are confident that climate change will affect the areal extent and distribution of wetlands, although at present it is not possible to estimate future areal size and distribution of wetlands from climate-change scenarios. Regional studies from east China, the United States, and southern Europe indicate that the area of wetlands will decrease if the climate becomes warmer. Climate warming also would have severe impacts on wetlands in arctic and subarctic regions in this respect because it would result in a melting of permafrost, which is the key factor in maintaining high water tables in these ecosystems.

Adaptation, conservation, and restoration of wetlands in response to climate change varies among wetland types and the specific function being considered. For regional and global functions (e.g., trace-gas fluxes and carbon storage), there are no human responses that can be applied at the scale necessary. For wetland functions that are local in scale (habitat value, pollution trapping, and to some degree flood control), possibilities exist for adaptation, creation, and restoration. However, wetland creation and restoration technologies are just developing, and we do not yet have reliable techniques to create wetlands for many specific purposes.

6.1. Introduction

6.1.1. Aims and Goals of the Chapter

This chapter examines the potential impacts of climate change on non-tidal wetland ecosystems and the possible options for responding to these changes. Tidal wetlands are covered in Chapter 9.

This chapter gives particular emphasis to the possible impacts of climate change on the areal extent, distribution, and functions of non-tidal wetlands, in the context of other natural or anthropogenic stressors that are likely to affect these ecosystems simultaneously. In addition to describing the importance of different climate variables and the range of factors that determine the sensitivity of individual wetlands, the chapter uses four case studies to illustrate the effects of climate change on certain defined wetland areas: the Sahel, northern boreal wetlands, Kalimantan (Indonesia), and the Florida Everglades.

This is the first time that IPCC has attempted a detailed assessment of the potential impacts of climate change on the structure and function of wetlands. Previous assessments briefly touched upon wetlands in a qualitative discussion of methane (CH_4) sources and sinks (Melillo *et al.*, 1990) and discussed wetlands in the context of ecosystem responses to increased CO_2 concentrations, illustrated by case studies of the arctic tundra and a salt marsh.

The present assessment is hindered because the literature on wetlands is highly variable in quality and coverage and large gaps in knowledge remain regarding many of their regulating processes. In particular, relatively few studies exist on the impacts of climate change on inland wetlands; most that do exist have been carried out on specific wetland sites and/or have tended to focus on the Northern Hemisphere. These factors are reflected in the examples and conclusions in this chapter and in the emphasis on case studies. Recently, wetlands and wetland-related topics have begun to receive increasingly greater attention, and new information is expected to be published in the near future.

6.1.2. Definition

Wetlands exist in both inland and coastal areas, covering approximately 4–6% of the Earth's land surface. A wide variety of wetland definitions are found in the literature. Cowardin *et al.* (1979) argue that there is no single, correct, indisputable, ecologically sound definition for wetlands, primarily because of the diversity of wetlands and because the demarcation between dry and wet environments lies along a continuum. In general, a wetland describes any area of land where the water table is at or near the surface for some defined period of time, leading to unique physiochemical and biological processes and conditions characteristic of shallowly flooded systems (Mitsch and Gosselink, 1993). This chapter will discuss both permanent and temporary wetlands.

6.1.3. Classification

Wetlands usually are categorized according to their characteristic vegetation; their location (coastal or inland); the salinity of the water they contain; or other biological, chemical, hydrological, and geographical features. Coastal wetlands are influenced by the ebb and flow of tides and may include tidal salt marshes, tidal freshwater marshes, and mangrove swamps (see Chapter 9).

This chapter covers inland wetlands, or those not subject to tidal influences—including peatlands, swamps, marshes, and floodplains. Peatlands consist of bogs and fens, which may be forested, and are peat-accumulating wetlands in moist climates (peat is partially decomposed plant material). Bogs are acidic, poor in nutrients, and receive water from precipitation only, whereas fens are generally circumneutral, richer in nutrients, and receive water primarily from overland flow and/or groundwater. Swamps or forested wetlands are areas with little or no peat accumulation. Marshes or herbaceous wetlands and floodplains are flooded areas along rivers or lakes (Zoltai and Pollet, 1983).

More than seventy global classification schemes exist internationally. Because the response of wetlands to climate change tends to be site- or region-specific, no existing scheme is useful for this chapter in relating geographic or physical features with climate responses. For this reason, this chapter will focus on describing the climate and other variables that determine the response of individual wetland sites, rather than attempting to correlate responses with particular wetland types.

Many studies have shown that hydrologic parameters are strong controllers of wetland ecosystem structure and function (Gosselink and Turner, 1978; Novitzki, 1989; Kangas, 1990). The source, renewal rate, and timing of the water regime directly control the spatial and temporal heterogeneity of wetland ecosystem structure and function. The hydroperiod—defined as the depth, frequency, duration, and season of flooding—is usually the single most important regulator in wetlands, controlling many of their important characteristics (Lugo *et al.*, 1990a). The hydroperiod is determined by the climate, topography, catchment area, soils, and geology of the region in which the wetland is situated (Armentano, 1990).

For this assessment, we focus on climate-change effects on hydrology as an integrative tool for our analysis. However, these effects are highly site-specific, and there are few general, categorical conclusions that can be drawn. There is extreme hydrological variation between and even within individual wetlands, such as differences in the direction of water flow (vertical, unidirectional, or bidirectional; Lugo *et al.*, 1990b). This variability, coupled with the resolution at which these hydrological differences can be found, reinforces the need to describe wetland responses on a site-by-site basis. It is possible to generalize impacts for specific wetland types and, to some degree, wetland regions, but it is difficult to generalize across different wetland types.

6.1.4. Global Distribution of Wetlands

Wetlands are found on every continent except Antarctica and in every climate from the tropics to the tundra (Mitsch and Wu, 1995; Mitsch and Gosselink, 1993). Matthews and Fung (1987) recently conducted extensive surveys to determine the distribution of wetlands on a global scale and estimate that wetlands account for an area of 5.3×10^6 km^2, or approximately 4% of the Earth's land surface (Figures 6-1 and 6-2). This estimate is similar to other recent estimates (e.g., Aselmann and Crutzen, 1989) but indicates a possible reduction from previous estimates of around 6% (Bazilivich *et al*, 1971; Maltby and Turner, 1983). However, any estimate of global coverage will depend significantly on the definition of a wetland that is used.

6.1.5. Current Wetland Stressors

Wetlands already are threatened by a range of environmental factors, which can be natural or anthropogenic. It is estimated that more than half of the world's wetlands have disappeared since 1900. In the lower 48 states of the United States, approximately 53% of the original wetland area has been lost; 87% of this loss is attributed to agricultural development, 8% to urban development, and 5% to other conversions (Maltby, 1986). The same is valid for most of the developed regions of the world. The status of wetlands in developing countries is currently unknown to a large extent, but population pressures in many regions are steadily increasing the demand for food (Dugan, 1988), which can lead to wetland loss due to agricultural development. Many wetlands, especially in tropical regions, have so far escaped the impacts of human activities owing to their remoteness and unsuitability for agriculture (see Section 6.5.4). However, in recent decades, population pressures and technological advances have extended human influences into previously undisturbed areas (Armentano, 1990). For example, in 1989 it was calculated that only 82% of Indonesia's peat swamp forests remained in their original condition (Silvius, 1989); for some provinces (e.g., South Sumatra), it is predicted that no swamp forest will be left by the year 2000 (PHPA and AWB, 1990). Table 6-1 summarizes the main causes of present-day wetland loss.

6.2. Global Importance of Wetlands

Wetlands have many functions that are considered to have socioeconomic value: They provide refuge and breeding ground for many species, including commercially valuable furbearers, waterfowl, and timber; they often contain a high diversity of species; they control floods and droughts and improve water quality; and they can be used for recreation and education. The socioeconomic value of wetlands will vary from region to region, depending on which wetland functions the local economies regard as valuable. Table 6-2 identifies wetland types with their values.

Some wetlands (usually peatlands) contain potential energy for human consumption. In developing countries with shortages of energy and fuel, peat harvesting can be an attractive financial proposition if extensive peat deposits are available. This can

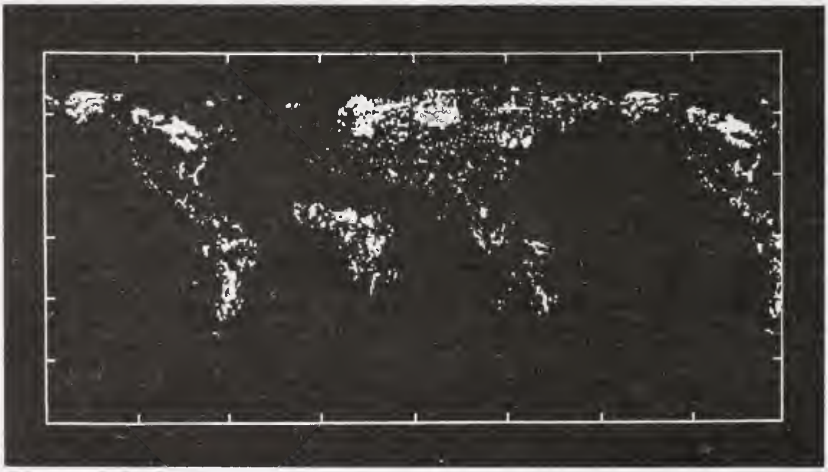

Figure 6-1: Global distribution of wetland ecosystems (modified after Matthews and Fung, 1987). Lighter areas denote wetlands.

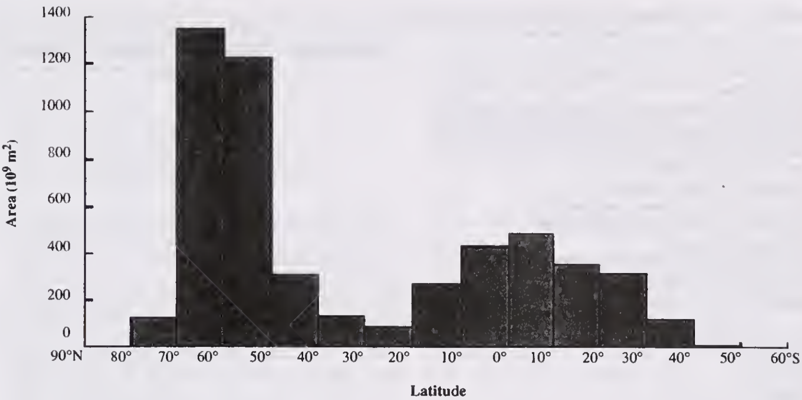

Figure 6-2: Distributions of wetland types along 10° latitudinal belts (modified after Matthews and Fung, 1987).

have the effect of replacing imported energy sources and reducing foreign-exchange requirements (Bord na Móna, 1985). However, large-scale harvesting of peat has led to the destruction of peatland ecosystems, and peat mining has the dual effect of removing a CO_2 sink (but a source of CH_4) and adding to the CO_2 in the atmosphere (see Rodhe and Svensson, 1995).

In the recent past, nonconsumptive benefits of wetlands such as recreation (Mercer, 1990), archaeology (Coles, 1990), education, and science usually were given lower priority in management plans than directly consumptive values because they are highly aesthetic and their values are difficult to quantify (Reimold and Hardinsky, 1979). However, these values have been given much greater attention in recent years, and wetlands worldwide are starting to be considered highly valuable areas to conserve.

6.2.1. Habitats and Diversity

The total biodiversity (flora and fauna) of wetlands generally is high in comparison with terrestrial ecosystems. Wetlands provide protective cover and essential feeding, breeding, and maturation areas for a wide range of invertebrates, as well as cold- and warm-blooded vertebrates (Gosselink and Maltby, 1990; Clark, 1979). Some animals are entirely dependent on wetland habitats; others are only partially so. In North America, for example, muskrats and beavers fall into the dependent group, whereas raccoons and various species of deer fall into the non-dependent one. In many areas, the remoteness and inaccessibility of wetlands has attracted species that may not be totally wetland dependent but take advantage of the protection and shelter they provide. For example, the Pantanal in Brazil, Paraguay, and Bolivia provides an important habitat for the jaguar (Dugan, 1993).

Probably the best known function of wetlands is as a provider of year-round habitats, breeding areas, and wintering sites for migratory birds, depending on their location (Bellrose and Trudeau, 1988; Dugan, 1993). One example is the prairie pothole region in the United States, where the value of the region as habitat for breeding birds, especially waterfowl, has been thoroughly documented. Annual production is correlated with the number of wet basins for many duck species (Boyd, 1981; Krapu *et al.*, 1983; Reynolds, 1987). More than half of the waterfowl production in North America occurs within this region (Batt *et al.*, 1989).

6.2.2. Biogeochemical Values

Wetlands play an important role in the global budgets of carbon (C) and the trace gases CH_4 and nitrous oxide (N_2O). Wetland soils represent a major pool of C that may respond dynamically to climate change (Woodwell *et al.*, 1995). Boreal wetlands, which are extremely susceptible to climate change, are a major contributor to the global CH_4 budget (Matthews and Fung, 1987).

Wetlands are efficient in trapping pollution and processing wastes in human-dominated landscapes. Wetlands have been found to be important "sinks" for pollutants moving from upland areas, preventing their movement into surface water and groundwater (Mitsch and Gosselink, 1993); indeed, artificial

Table 6-1: Causes of wetland losses (modified after Dugan, 1990).

	Floodplains	Marshes	Peatlands	Swamps
Human Actions				
Drainage for agriculture, forestry, and mosquito control	++	++	++	++
Stream channelization for navigation and flood protection		+		
Filling for solid waste disposal, roads, etc.	++	++		
Conversion for aquaculture	+	+		
Construction of dikes, dams, and levees	++	++		
Discharge of toxic compounds and nutrients	++	++		
Mining for peat, coal, gravel phosphate, etc.	+		++	++
Groundwater abstraction	+	++		
Sediment diversion by dams, deep channels, etc.	++	++		
Hydrological alterations by canals, roads, etc.	++	++		
Subsidence due to extraction of groundwater, oil, gas, minerals, etc.	++	++		
Natural Causes				
Subsidence			+	+
Sea-level rise				++
Drought	++	++	+	+
Hurricanes and storms			+	+
Erosion	+		+	
Biotic effects	++	++		

Notes: ++ = common and important cause of wetland loss; + = present but not major cause of wetland loss.

Table 6-2: Wetland values (modified after Dugan, 1990).

	Floodplains	Marshes	Peatlands	Swamps
Function				
Groundwater recharge	++	++	+	+
Groundwater discharge	+	++	+	++
Flood control	++	++	+	++
Erosion control	+	++		
Sediment/toxicant retention	++	++	++	++
Nutrient retention	++	++	++	++
Biomass export	++	+		+
Storm protection	+			
Microclimate stabilization	+	+		+
Water transport	+			
Recreation/tourism	+	+	+	+
Products				
Forest resources	+			++
Wildlife resources	++	++	+	+
Fisheries	++	++		+
Forage resources	++	++		
Agricultural resources	++	+	+	
Water supply	+	+	+	+
Attributes				
Biological diversity	++	+	+	+
Uniqueness to culture	+	+	+	+

Notes: ++ = common and important value of that wetland type; + = less common and important value.

wetlands are being used to treat wastewater. Declines in these functions due to climate change could have important economic and aesthetic implications, particularly in heavily developed areas (Arheimer and Wittgren, 1994).

6.3. Sensitivities and Impacts

6.3.1. *Which Wetlands are Most Vulnerable to Climate Change?*

It is difficult to determine the vulnerability of specific types of non-tidal wetlands to climate change. One line of reasoning suggests that wetlands in naturally stressed environments appear to tolerate less additional stress than those located in favorable conditions (Lugo and Brown, 1984), meaning that they are more vulnerable to the alterations in hydrological regimes that are expected to result from climate change. By this reasoning, depressional wetlands (found in depressions in the landscape) with small watershed areas and situated in areas where the climate is either dry or wet at present will be most susceptible to these effects (Mitsch and Wu, 1995). In contrast, wetlands along floodplains and lakes should be able to adapt to a changing climate by migrating along river edges up- and downstream as well as up- and downslope to follow water—although the efficiency of such migration will be dependent on a number of factors, including catchment area, topography, and human settlements.

A second line of reasoning suggests that wetland types that have a large degree of inherent exposure to high spatial and temporal variation in environmental conditions may have a greater potential for adaptation to climate change (see Section 6.4).

Arctic and subarctic peatlands will be extremely vulnerable to climate change if warmer temperatures lead to a thawing of the permafrost layer and affect their hydrology through drainage or flooding (Gorham, 1994; Oechel and Vourlitis, 1994; OTA, 1993). These wetlands have a limited capacity to adapt to climate change because it is unlikely that new permafrost areas will form. In addition, non-tidal wetlands located near the coast are vulnerable to changes in climate due to sea-level rise, which would have severe impacts resulting from chemical and hydrological changes caused by intrusion of saline seawater (see Section 6.5.5).

6.3.2. *Importance of Different Climate Variables*

No single factor determines how climate change will affect individual wetland ecosystems. The variables that are predicted to change include temperature, precipitation, and CO_2 concentrations, resulting cumulatively in changes in water availability. Changes in the frequency and duration of flooding and drought and any alterations in disturbance regimes will be particularly important in determining how the ecological functions of wetlands ultimately are affected.

6.3.2.1. *Temperature*

Temperature is an important factor controlling many of the ecological and physical functions of wetlands. Primary productivity, microbial activity, and habitat are all controlled to a certain extent by temperature. Temperature also affects evapotranspiration rates, which has implications for the hydrological regime of wetlands by transporting water from the ecosystem to the atmosphere.

6.3.2.2. *Precipitation*

Precipitation regulates the direct inflow and amount of water to wetland ecosystems. However, the effect of a change in precipitation on a given wetland will depend on the type of wetland and the topographic and geographic characteristics of the region (drainage area, relief, and so forth). For example, very large wetlands, like the Okawango delta in Africa, are supplied with water from a considerable distance. In this case, the spatial variability of climate change could affect the balance between supply and evaporative demand. Further, in wetlands located along floodplains, a change in water availability throughout the drainage area or region will affect flooding and the hydrological regime in complex ways.

Poiani *et al.* (1995) show that the seasonality of precipitation changes is very important to wetland ecosystems. Climate change affecting spring precipitation and runoff may have the greatest impact on wetland hydrology and vegetation. Some modeling studies have indicated that there may be a threshold temperature beyond which changes in precipitation become less important to wetland hydrology. In one study, Poiani and Johnson (1993) conclude that precipitation changes are much less influential on hydrological regimes under a +4°C scenario than under a +2°C scenario.

6.3.2.3. *CO_2 Concentration*

Current research suggests that elevated CO_2 levels may have a direct fertilization effect on some types of vegetation, leading to higher production rates (Idso and Kimball, 1993). Elevated CO_2 concentrations seem to increase plant tolerance to stress, including photoinhibition, high or low temperature extremes, drought, and waterlogging (Hogan *et al.*, 1991). However, multi-species, intact ecosystems may show complex responses to an increase in CO_2 concentrations (Korner and Arnone, 1992). Elevated CO_2 concentrations in the atmosphere also may affect the rate of evapotranspiration through changes in water usage by plants (Bunce, 1992; Kimball and Idso, 1983). However, the effects of increased CO_2 on transpiration and water-use efficiency appear to decrease as water availability increases or as temperature decreases (Oechel and Strain, 1985). Any changes in transpiration may influence regional water balances and hydrological regimes because vegetation is a critical component of the cycling of water between soils and the atmosphere (Salati and Vose, 1984). Until detailed mechanistic questions regarding the biochemistry and physiology of wetland vegetation can be resolved, the extent to which wetlands will respond to increased CO_2 concentrations remains uncertain (Larson, 1994).

6.3.2.4. *Extreme Events*

Wetlands are sensitive to extreme climate events such as heavy spring flooding and summer drought (Gorham, 1991). Potential changes in precipitation patterns related to the amplitude, periodicity, or frequency of extreme events are critical components in modeling wetland responses to climate change (Poiani and Johnson, 1993). Extreme droughts make wetlands more sensitive to fire (see Sections 6.5.4 and 6.5.5; Gorham, 1994), which could impact ecological functions such as vegetation cover, habitat value, and carbon cycling. At the same time, such biomass burning is likely to result in massive emissions of smoke particles (aerosols) to the atmosphere, which may offset some warming, at least regionally (Penner *et al.*, 1992). Sea-level rise may affect some inland wetlands, causing saltwater intrusion that could result in an encroachment of salt-tolerant wetland communities.

6.3.2.5. *Water Availability and Movement*

Combined changes in temperature, evapotranspiration, precipitation, and CO_2 concentrations ultimately affect the hydrologic regime in a wetland ecosystem. It is critical to consider these combined effects because responses can be nonlinear. For example, it has been found that relatively small differences in precipitation can produce substantial differences in water level, especially for smaller temperature increases (Poiani and Johnson, 1993). Whereas decreased water availability will cause wetland loss due to concomitant drying, climate models suggest that some areas will become wetter—particularly high-latitudes in the winter. Although few studies have examined the potential impacts in these cases, it is conceivable that wetter conditions could be conducive to wetland development in areas not currently occupied by wetlands—as has occurred in areas of the Sahel (see Section 6.5.2).

In some cases, the movement of water in itself can benefit wetlands because it contributes to nutrient transport, aeration, and so forth, and because species can more readily distribute themselves according to the hydrological conditions to which they are adapted. Floods also create currents capable of exporting toxic compounds that otherwise could accumulate in sediments (Lugo *et al.*, 1990a). However, extremely intense hydrological fluxes tend to stress wetland ecosystems.

6.3.3. *Effects on Wetlands Due to Climate Change*

Climate changes affecting the areal extent, distribution, and hydrological regimes of wetlands are expected to have important effects on their ecological functions. These effects must be assessed in light of many uncertainties, particularly concerning the interactions of atmospheric water, surface water, and groundwater components of wetlands (Winter, 1988).

6.3.3.1. *Areal Extent and Distribution*

At present, regional scenarios do not provide adequate information to determine the direction or magnitude of change in the areal extent of wetlands (Gorham, 1991). It seems likely that some wetland regions will become moisture-limited, while other non-wetland areas will develop a climate conducive for wetland development. At this time, however, any estimation of the change in global areal extent would be very uncertain (see Gorham, 1991).

A few studies have attempted to estimate possible regional changes in wetland distribution, although they tend to involve areas that are projected to experience net losses in water availability rather than areas that are expected to experience increases. For example, a study by Brock and van Vierssen (1992) of hydrophyte-dominated wetlands in southern semi-arid regions of Europe concludes that an increase in temperature of 3–4°C would decrease the areal extent of habitat for hydrophytes by 70 to 85% within 5 years—suggesting that wetlands in other semi-arid and arid regions will be very sensitive to climate warming (see Section 6.5.2).

Poiani and Johnson (1993) conducted a study to understand how possible changes in the areal extent of a semipermanent wetland in the prairie pothole region of the United States might affect its ecological functions. For this study, they developed a simulation model for hydrological and vegetation responses. Using output from the Goddard Institute for Space Studies (GISS) general circulation model (GCM) for current and doubled-CO_2 climates (mean monthly air-temperature increase of 3 to 6°C and precipitation ranging from -17% to +29%) in an 11-year simulation, they project a 3% increase in the overall size of this wetland under current climate but a decrease of nearly 12% under the greenhouse scenario. Further, the areas of open water would decrease from 51% at the beginning of the simulation to 0% by the fourth year, allowing emergent plant species to spread over the entire wetland. This change would have serious implications for the wildlife in the region because these areas are extremely important breeding areas for waterfowl (see Section 6.2.1). This study indicates that even if the total decrease in wetland area due to a warmer climate is relatively small (12%), the overall change in wetland characteristics can have severe effects on many of the existing functions and values of wetlands. The model also indicates that wetland size, depth, and vegetative characteristics are more sensitive to changes in temperature than to either increases or decreases in precipitation.

Another study of the prairie pothole region (Larson, in press) examines the relationship between climate variables and the percentage of wet basins, using a multiple linear-regression model. This study focuses on closed-basin wetlands surrounded by either grassland or aspen parkland. The study found that when temperatures increase by 3°C in subsequent model runs

(15 years simulated), the Canadian and U.S. grassland models project declines in the percentage of wet basins of 15% and 28%, respectively. The aspen parkland model, however, projects a decline of 56% in the number of wet basins with increased temperatures. Model response to changes in precipitation were uniform and small across the region. An important consequence of geographical differences in wetland response to temperature is that as waterfowl extend their migrations farther north in drought years, they may face decreased probability of finding suitable wetlands.

A study by Zhang and Song (1993) examines the possible effects of climate change on the areal extent of the wetlands of eastern China, where 75% of the country's wetlands are located. The study examines climate change under six hypothetical climate scenarios (precipitation increasing or decreasing by 10% and temperature increasing 1, 2, and 3°C); the areal extent of herbaceous wetlands declines under all scenarios.

At high northern latitudes, warming could cause a poleward migration of the northern treeline. This shift would decrease the winter albedo because the tree canopy has much lower albedo than exposed snow surfaces (Bonan *et al.*, 1992), greatly affecting regional climate by absorbing more of the sun's incoming energy.

Another implication for northern peatlands is the expected melting of permafrost due to higher temperatures (see Chapter 7). Harriss (1987) concludes that an increase in temperature of 2°C would shift the southern boundary of permafrost in the Northern Hemisphere to the north. The melting of permafrost is likely to have drastic effects on peatland hydrology and landscape patterns, leading to lowered water tables in some areas and flooded thaw lakes in others, as well as to thermokarst erosion (Billings, 1987; Gorham, 1991). It has been suggested (Zoltai and Wein, 1990) that such melting may shift bogs on permafrost back to fens, from which they originated after the warm mid-Holocene period. Vegetetation could shift from black spruce/Sphagnum/lichen (which are typical for bog ecoystems) to grasses, sedges, and reeds. Further, the rate of climate-change impacts on northern peatlands may be such that it causes degradation of southern regions much faster than the northern regions can expand northward (Gorham, 1991). These shifts also would have implications for the carbon cycle, as well as the flux of especially CH_4 from northern peatlands (see Section 6.5.3).

6.3.3.2. Functions

Functions are processes necessary for the self-maintenance of ecosystems, such as primary production, nutrient cycling and decomposition. Wetland functions can be categorized as biological, biogeochemical, or hydrological. These are distinct from, but often translate into, the socioeconomic values perceived by society (Brinson, 1993). None of these categories is exclusive, and each may influence the other; for example, any changes in wetland plant species have far-reaching effects on a wide range of wetland functions due to the unique structural, chemical, and ecological characteristics of different plants.

6.3.3.2.1. Biological functions

Biological functions relate to vegetation, habitats, and species diversity. Climate changes resulting in increased or decreased temperature and water availability will affect the composition and production of vegetation, the quality and areal extent of habitat available for species, and species composition and diversity (Thompson and Hamilton, 1983; Junk, 1983, 1993; Bradbury and Grace, 1983; Reader, 1978; Bernard and Gorham, 1978).

The species composition of plant communities in wetlands is critically affected by water movement and hydroperiod (Lugo *et al.*, 1990a). Often, extended flooding and a longer hydroperiod will result in tree mortality and the replacement of forest by herbaceous vegetation (Lugo *et al.*, 1990a). A long-term lowering of the water table would probably lead to similar changes in the composition and production of the vegetation as found in drainages made for forestry (e.g., in Sweden and Finland).

In forested wetlands subjected to drainage, the lowering of the water table has resulted in an increase in tree-stand volume (Keltikangas *et al.*, 1986; Hånell, 1988). Based on data from several different wetland types given by Hånell (1988), Rodhe and Svensson (1995) calculate that the increase in tree-stand volume could range between 1.2–6.0 kg dry biomass/m². Similar results are reported in studies on wetlands in Finland (Ilvessalo and Ilvessalo, 1975).

Changes in wetland plant communities can have important effects on decomposition, nutrient cycling, and plant production functions. The nature and amount of plant litter production strongly influences wetland soil microbial populations (Melillo *et al.*, 1982; McClaugherty *et al.*, 1985; Bowden, 1987). Several studies have found strong links between wetland plant community types and microbial decomposition and nutrient-cycling processes in fens and bogs (Svensson, 1976, 1980; Svensson and Rosswall, 1984; Verhoeven *et al.*, 1990; Verhoeven and Arts, 1992; van Vuuren *et al.*, 1992, 1993; Koerselman *et al.*, 1993). Microbial decomposition of litter and the release or "mineralization" of nutrients contained therein enhances plant productivity and litter quality (nutrient content, degradability; Pastor, 1984). Different plant communities demonstrate different rates of nitrogen availability to plants, carbon storage, and microbial processing of pollutants (Rosswall and Granhall, 1980; Pastor *et al.*, 1984; Morris, 1991; Duncan and Groffman, 1994; Weisner *et al.*, 1994; Schipper *et al.*, 1994).

The physical and chemical characteristics of plants also strongly influence insect species and populations, which provide life-support functions for wetland-dependent birds, fish, and mammals (Mitsch and Gosselink, 1986; Kiviat, 1989). In conservation biology, there is intense interest in the effects of changes in plant species on the habitat value of wetlands (Bratton, 1982; Harty, 1986; Mooney and Drake, 1986; Center *et al.*, 1991; McKnight, 1993).

6.3.3.2.2. *Biogeochemical functions*

Biogeochemical functions include pollution trapping and waste processing, carbon cycling (Svensson, 1986; Armentano and Menges, 1986; Silvola, 1986; Sjörs, 1980; Gorham, 1990, 1991; Miller *et al.*, 1983; Marion and Oechel, 1993), and the flux of greenhouse gases (Svensson *et al.*, 1975; Svensson, 1976; Aselmann and Crutzen, 1989; Matthews and Fung, 1987; Bartlett and Harriss, 1993; Matthews, 1993; Bartlett *et al.*, 1989; Urban *et al.*, 1988; Freeman *et al.*, 1993; Martikainen *et al.*, 1993; Pulliam, 1993).

Wetlands, and especially peatlands, play a significant role in the carbon cycle and presently are net sinks of carbon. A recent compilation of estimates of the amount of carbon held in soil as organic matter (Woodwell *et al.*, 1995) gave a mean of 1,601 Gt, of which about 20% (412 Gt of C) is stored in peatlands. Estimated average accumulation rates for boreal and subarctic peatlands range from 0.05–0.11 Gt C/yr (Armentano and Menges, 1986; Silvola, 1986; Sjörs, 1980; Gorham, 1990, 1991; Miller *et al.*, 1983; Marion and Oechel, 1993). However, some peats may have reached a balance between the degradation and addition rates of organic matter (Malmer, 1992; Warner *et al.*, 1993).

Laboratory experiments and field studies have shown that lowering the water table by 20–30 cm could increase CO_2 fluxes from peat soil 1.5–2.5-fold (Silvola *et al.*, 1985; Moore and Knowles, 1989). However, it seems that changes in the water table are more significant between 0–30 cm than between 30–60 cm (Silvola *et al.*, 1985). Any lowering of the water table would mean, on the average, an extra carbon release of about 100–300 g C/m²/yr. Further, an increase in temperature of 1–5°C in northern peatlands could decrease carbon accumulation by 10–60% due to enhanced microbial activity (see Section 6.5.3). Very little is known about peatlands in tropical regions, and there is some disagreement about whether tropical peatlands at present function as net carbon sinks or sources (Immirzi and Maltby, 1992; Sorensen, 1993; Sieffermann *et al.*, 1988; see Section 6.5.4). They are, however, large carbon stores, and any significant changes in the degree of storage have implications for carbon cycling.

In the recent geologic past, the tundra was a sink of 0.1–0.3 Gt C/yr (Miller *et al.*, 1983; Marion and Oechel, 1993). However, recent climatic warming in the arctic (see Lachenbruch and Marshall, 1986; Chapman and Walsh, 1993), coupled with the concomitant drying of the active layer and the lowering of the water table, has shifted areas of the arctic from sinks to sources of CO_2 (Oechel *et al.*, 1993). For example, arctic areas that were sinks of 0.1 Gt C/yr now are sources of 0.1–0.6 Gt C/yr (Oechel *et al.*, 1993; Zimov *et al.*, 1993). This illustration of a response of a northern wetland to warming suggests a major change in ecosystem function that may be an early indication of global change in a natural ecosystem.

Although wetland vegetation fixes atmospheric CO_2, biogeochemical processes give rise to other greenhouse gases, such as CH_4. The estimated contribution of wetlands to the annual atmospheric CH_4 burden is 55–150 Mt/yr (Prather *et al.*, 1994). However, the flux measurements on which these estimates are based are biased toward wetlands in northern North America and the Scandinavian countries (Bartlett and Harriss, 1993; Matthews, 1993). Climate change leading to an alteration in the degree of saturation and flooding of wetlands would affect both the magnitude and the timing of CH_4 emissions (see Section 6.5.3.2). Drying of northern wetlands could lead to declines in CH_4 emissions (Roulet *et al.*, 1993; Martikainen *et al.*, 1995). Although emissions of N_2O from wetlands usually are low (Urban *et al.*, 1988; Freeman *et al.*, 1993; Martikainen *et al.*, 1995), a lowering of the water table could increase emissions.

Climate change also can affect the chemical properties of wetlands. Some non-tidal wetlands are saline due to the surplus of evapotranspiration over precipitation. If rates of evapotranspiration increase, there is a risk that more salts will accumulate in these wetlands, which could impair the value of wetlands due to the loss of intolerant species. Wetlands that are presently freshwater could become saline. However, in regions facing a decrease in evapotranspiration, the existing saline wetlands could gradually change as salinity decreases. This will affect the chemical properties of the wetlands—which, in turn, has consequences for biological and ecological characteristics, affecting vegetation, habitat value, and species composition (including the invertebrate community; Swanson *et al.*, 1988).

An increase in temperature also will affect processes such as pollution trapping and waste processing because these processes are regulated by microbial activity and plant uptake, which are important sinks for nutrients (such as nitrogen and phosphorus) and various kinds of pollutants (heavy metals, pesticides and herbicides; Gilliam *et al.*, 1988; van der Valk *et al.*, 1979; Brinson, 1990; Brix and Schierup, 1989; Johnston, 1991; Mitsch and Gosselink, 1993). However, the key features to which these water-quality functions are connected are coupled to the water regimes of wetlands (Kadlec, 1989), so it is impossible to make any general statements about the impact of climate change on these functions.

6.3.3.2.3. *Hydrological functions*

Hydrological functions include flood control (Andriesse, 1988; Novitzki, 1979; Boelter, 1966; Gosselink and Maltby, 1990) and aquifer recharge (Bernaldez *et al.*, 1993). Wetlands temporarily store runoff water, thereby reducing floodwater peaks and protecting downstream areas (Andriesse, 1988; Novitzki, 1979; Boelter, 1966; Gosselink and Maltby, 1990). A reduction of wetland area due to climate change could severely hamper flood-control efforts in some regions. Under certain conditions, climate change could enhance recharge to major aquifers by overlying wetlands—particularly in arid or semi-arid regions, where groundwater is of considerable importance as a source for public water supply and irrigation (Bernaldez *et al.*, 1993; see Section 6.5.2). The contribution of wetlands to groundwater resources depends on the detention of water within the wetland during dry periods; this is likely to be reduced by loss of wetlands (Bernaldez *et al.*, 1993).

At northern latitudes, projected higher spring and winter temperatures would likely affect the amount and timing of runoff from snowmelt and rainfall by changing the patterns of soil freezing and thawing (Mimikou *et al.*, 1991). It also would decrease the ratio of snow to rain, leading to additional changes in spring snowmelt (Cohen, 1986; Gleick, 1987; Croley, 1990).

6.3.4. Interactions Between Climate Change and Other Wetland Stressors

The impacts of climate change on wetlands will interact with other anthropogenic stresses. Due to the importance of hydrological regime and wetland response, we confine ourselves to discussing the cumulative impacts of hydrological changes in wetlands. Apart from climate change, the most common disturbances to the hydrological regimes of wetland ecosystems are alterations in plant communities, storage of surface water, road construction, drainage of surface water and soil water, alteration of ground water recharge and discharge areas, and pumping of ground water. All of the anthropogenic activities and natural causes mentioned in Table 6-1 will, to various extents, impact the hydrology of wetlands. Drainage for agriculture, for example, would cause drastic changes in water level and means near-total destruction of wetland ecosystems, whereas construction of dams for water management could be less severe if efforts to maintain waterflow through the subjected wetlands are made. Due to site-specific responses by wetland ecosystems and the large range of plausible anthropogenic and natural stressors, a quantitative evaluation of them in combination with climate change is difficult. It is conceivable, however, that within the next decades the main threat to wetlands is likely to be due to anthropogenic activities rather than climate change.

6.4. Response Options—Adaptation, Conservation, and Restoration

The prospects for adaptation, conservation, and restoration of wetland ecosystems in response to climate change varies with wetland type and the specific wetland function being considered. For wetland functions that are an aggregated product of regional or global wetland resources (e.g., trace-gas fluxes, carbon storage), there are no human responses that can be applied at the necessary scale. Moreover, changes in these functions as wetlands adapt to climate change are difficult to predict due to the site-specific nature of wetland responses to climate change.

For wetland functions that are more local in scale (e.g., habitat value and pollutant absorption), prospects for adaptation, conservation, and restoration are better than for large-scale functions. However, these prospects will vary strongly with wetland type. Some wetland types have a higher potential for adaptation to climate change due to their inherent exposure to high spatial and temporal variation in environmental conditions. For example, the prairie pothole wetlands discussed in Section 6.3.3.1 respond dynamically and naturally to wide variation in seasonal and annual climate (van der Valk and Davis, 1978; Poiani and Johnson, 1989).

Other wetland types—for example, boreal peatlands—have high spatial variability in plant communities caused by variation in macro- and microtopography (Sjörs, 1950). Hotter, drier, and/or wetter climates will result in a change in the wetland community in these wetlands, but the natural spatial and temporal variation inherent in these systems suggests that the changed community will resemble at least some component of the existing community (Poiani and Johnson, 1989).

Given the site-specific nature of wetland responses to climate change and the importance of inherent variation in fostering potential for adaptation, wetland conservation and restoration efforts should focus on preserving this variation (McNeely, 1990; Leemans and Halpin, 1992; Peters and Lovejoy, 1992). Wetland restoration and creation technologies have a great potential for ameliorating the effects of climate change on wetland functions. However, wetland ecology is complex, and the enthusiasm for wetland creation and restoration has outpaced the scientific understanding and technological development needed to successfully create wetlands for specific purposes (Reed and Brown, 1992; van der Valk and Jolly, 1992). Key areas of concern in wetland creation are how to establish a persistent and resilient assemblage of desired wetland plants, and a lack of understanding of the relationships between different plant assemblages and a range of wetland functions—from microbial pollutant-attenuation mechanisms to sequestration of soil carbon to food-chain support (Zedler and Weller, 1990; Pickett and Parker, 1994).

6.5. Examples and Case Studies

6.5.1. Introduction

This section uses case studies from certain defined wetland areas and regions to demonstrate climate-change impacts on different wetland types and geographic locations. The areas selected for these studies are the Sahel region of Africa, northern wetlands, the Kalimantan of Indonesia, and the Florida Everglades of the United States. These different locations will provide insight into the uses and responses of peatlands, marshes, and floodplains, as well as measures that are presently being taken in some places to restore wetlands affected by human uses and alterations.

The purpose of the case studies is to illustrate the general concepts described in this chapter through specific examples and to identify factors that make wetlands more or less vulnerable to any possible changes. The case studies also illustrate the type of information needed for any given location in order to conduct an assessment of potential risks, as well as the specificity of the information that may be gleaned about possible impacts at this time at individual sites.

Most of the case studies deal with the local functions, uses, and benefits of the wetlands and how these will be affected by climate change: These wetlands are valuable to nearby populations as sources of water, as agricultural land, as habitat for species, and for their other hydrological functions. Some of the case studies deal with the biogeochemical functions of wetlands and the ways in which human alterations and climate-change impacts on wetlands could affect the cycling of CO_2, CH_4, and N_2O to the atmosphere, which would result in global-warming feedback.

6.5.2. *Case Study: The Sahel*

6.5.2.1. *Background*

The Sahelian wetlands are dynamic ecosystems (see Box 6-1). During the past 2 decades, new wetlands of up to 1,800 hectares have formed, while other wetlands have been degraded (Piaton and Puech, 1992; Brouwer and Mullié, 1994a). Wetlands in the Sahel include the floodplains of the large rivers and Lake Chad, as well as thousands of small permanent and temporary wetland ecosystems scattered throughout the region (see Sally *et al.*, 1994; Brouwer and Mullié, 1994a; Windmeijer and Andriesse, 1993). Some of these wetlands, such as the small valley bottoms, contain water only during runoff events.

The small wetlands in the Sahel are very important for agriculture (MHE-DFPP, 1991; MHE-Niger, 1991a; Brouwer and Mullié, 1994b) and are used for dry-season cropping, using moisture left in the soil after the floods have receded, or for small-scale irrigation. In the period 1984–91, between 42,000 and 64,000 hectares of wetlands were used each year in Niger for dry-season cropping, generating an annual income of \$200–\$4,300 per hectare (MAE-Niger, 1993; Raverdeau, 1991; Cherefou Mahatan, 1994). In 1990, 4.1×10^6 hectares of dryland cropping (mostly millet) in Niger generated an income of about \$70 per hectare. This difference in income per hectare is in part a reflection of the quality of the food produced. The small wetlands also have greater production of fish per hectare and greater density of birds than the large wetlands (Brouwer and Mullié, 1994b; Mullié and Brouwer, 1994).

6.5.2.2. *Societal Context*

The human carrying capacity of the Sahel region is already matched or exceeded by population density (van der Graaf and Breman, 1993); dryland agriculture or large-scale migration to other parts of the region are unlikely to be able to relieve the situation. As a result, wetlands will be more sought-after, and pressure for conversion of wetlands to rice fields should increase due to increasing urbanization in West Africa and its effects on the demand for rice.

Droughts also tend to increase pressure on wetlands because they affect the migration patterns of people in the area. During the severe droughts of 1975 to 1988, the number of villages on the Nigerian section of Lake Chad increased from 40 to more than 100 (Hutchinson *et al.*, 1992). Similarly, the use of the Hadejia-Nguru wetlands in Nigeria for agriculture has increased due to droughts. This increase was not foreseen when plans were made for the construction of dams and irrigation projects in the catchment upstream. Wet periods have traditionally meant migration to the normally drier and less-populated northern and western parts of the Département Tahoua, Niger. Because these people often stayed despite less-abundant

Box 6-1. The Wetlands of the Sahel: Effects on Agriculture, Habitat, and Hydrology

Background: The wetlands of the Sahel region of Africa consist of the floodplains of major lakes and rivers, as well as thousands of smaller wetland ecosystems scattered throughout the region. These smaller wetlands are particularly important for agriculture and as a source of income from agriculture; floodplains are important for their hydrological functions. The wetlands in the Sahel are already expected to come under increased pressure for conversion to agriculture and other uses due to urbanization and population growth projected over the next decades.

Possible impacts: With the possible exceptions of eastern Niger and Chad, climate change is expected to decrease the extent of wetlands in the Sahel, due to changes in temperature and precipitation projected by current scenarios. These changes are likely to result in a net loss of water in most of the large rivers in the Sahel over the next 30–60 years, with the exception of the major rivers flowing into Lake Chad. Although few studies exist on the effects on species, the loss of wetlands due to climate change could create a risk of extinction for some local populations of turtles and birds.

Conclusion: Although climate change could have some beneficial effects on the wetland regions of the Sahel, there would be many adverse impacts; some could be potentially irreversible. Even if the predicted decrease in rainfall in the western Sahel were followed by a recovery to present levels or more, part of the damage that is likely to occur in the interim would be very difficult to repair.

rainfall, they increased the pressure on natural resources, including wetlands (DDE-Tahoua, 1993).

6.5.2.3. *Climate Change Expected*

Rainfall in the Sahel region is greater in the north than in the south (see Nicholson, 1978, 1994; Hutchinson *et al.*, 1992). This analysis focuses on the wet season (June–August), when most dryland crops are grown. According to the IPCC Working Group II scenarios (Greco *et al.*, 1994), precipitation in the Sahel zone is projected to decrease by 2020 in the Senegal to Burkina area and increase moderately to considerably in Niger and Chad. Temperature is projected to increase by 0.5–1.5 (0–2.0)°C. For the decade around the year 2050, the three models show less agreement overall, although all indicate that eastern Niger is likely to receive more rain. Temperatures would be similar to those around the year 2020, though possibly somewhat higher in the area of the headwaters of the Senegal and Niger rivers. In the headwaters of the Komadougou Yobé river, rainfall around the year 2020 is expected to be somewhat less than at present. For the year 2050, the scenarios are less conclusive: In the area of the headwaters of the major rivers flowing into Lake Chad, rainfall around 2020 and 2050 is expected to be moderately to considerably greater than now.

6.5.2.4. *Effects on Water Availability and Vegetation*

Overall, these changes suggest that there will be less water in most of the large rivers in the Sahel over the next 30–60 years, with the exception of the major rivers flowing into Lake Chad. This will mean less water available in the floodplains along these rivers, unless there are changes to the management of outflow from dams. Changes to the hydrology of the small wetlands will depend not only on climate change but also on whether they are supplied with surface water or groundwater, on the reaction of the natural vegetation, and on the extent of cropping in their catchment areas.

Recharge to shallow, unconfined groundwater could either increase or decrease as a result of climate change. The groundwater level in southwest Niger increased in the last decade (Leduc *et al.*, in press; Bromley *et al.*, in press a), either as a recovery from the droughts of 1983–84 and/or 1973–74 or as a response to changes in land use. Annual recharge under millet in southwest Niger is on the order of 1–200 mm, a factor ten times greater than under bush and older fallow vegetation (Gaze *et al.*, in press; Bromley *et al.*, in press b). Therefore, an increase in the area sown for millet—as noted by Reenberg (1994) and others—could result in a higher recharge to unconfined groundwater and the wetlands fed by such groundwaters.

The dryland areas should experience less evaporative water loss because less rainfall, at least initially, means less perennial vegetation. However, there will be increased runoff until a new vegetative cover is established. This increase in runoff will likely result in increased erosion (see van Molle and van Ghelue, 1991) and a faster silting up of wetlands. It also could create entirely new wetlands.

Higher temperatures also may adversely affect seedling emergence of millet, the staple cereal over much of the Sahel (see Monteith, 1981)—meaning that less millet would be harvested in the dryland areas and increasing the pressure on wetlands. However, during dry years in eastern Niger, infiltration into the heavier soils in depressions may be so low that cropping becomes unattractive (Reenberg, 1994). During dry years, water is more limiting than nutrients, and cropping on less-fertile upland soils with higher infiltration rates may become more attractive.

Desertification upon drought may result in a loss of wetlands due to moving sands (DDE-Tahoua, 1993; Mahamane Alio and Abdou Halikou, 1993; Framine, 1994). In part, this response can be related to the greater vulnerability of perennial vegetation to desiccation under a monomodal semi-arid rainfall regime (Ellis and Galvin, 1994), when topsoil and seedbanks are washed or blown away during the drought. Droughts may make wetland vegetation more vulnerable to fires intended to improve rangeland vegetation (Hutchinson *et al.*, 1992).

6.5.2.5. *Effects on Biodiversity*

There are few assessments of how these changes could affect local biodiversity. Mullié and Brouwer (1994), following Gibbs (1993), suggest that small wetlands in the Sahel are important for the metapopulation dynamics of certain taxa—meaning that the loss of small wetlands may lead to a significant risk of extinction for local populations of turtles and small birds (Gibbs, 1993). Taxa that are easily transported by wind or birds as adults, eggs, cysts, larvae, and so forth would be subject to less risk (Dumont, 1992; Mullié and Brouwer, 1994; Magadza, 1994).

The importance of wetlands to birds in semi-arid areas can vary greatly from year to year depending on local and regional rainfall (Rose and Scott, 1994). If wetlands in the western Sahel become drier, relatively mobile birds dependent upon wetland habitats will move into wetlands further east (i.e., Niger, northern Nigeria and Cameroon, Chad).

6.5.3. *Northern Wetlands: Effects on the Carbon Cycle and Trace-Gas Emissions*

6.5.3.1. *Peat Accumulation*

Peatlands are a major store of organic carbon and contain approximately 20% of the total amount of organic carbon stored in soils (see Section 6.3.3.2). A majority of this is in the Northern Hemisphere as carbon stored in the form of peat (see Box 6-2). Peat formation and accumulation in these wetlands is influenced by climate change: A change in climate would lead to changes in the flux of carbon (CO_2 and CH_4) between these ecosystems and the atmosphere, generating a feedback on climate warming.

Box 6-2. Northern Wetlands: Effects on the Carbon Cycle and Trace-Gas Emissions

Background: Peatlands are a major store of organic carbon and contain approximately 20% of the total amount of organic carbon stored in soils. The northern peatlands account for a majority of this as carbon is stored in the form of peat. This case study demonstrates how changes in climate may affect the flux of carbon (CO_2 and CH_4) and nitrous oxide between these ecosystems and the atmosphere, generating a feedback on climate warming.

Possible impacts: Current scenarios suggest that climate change is likely to increase the flux of CO_2 to the atmosphere because temperatures influence whether carbon litter is accumulated into the peat profile or oxidized. In addition, the position of the water table regulates the extent of oxygen penetration into the peat profile. This means that drainage will cause increased decomposition, leading to increased fluxes of CO_2 to the atmosphere, although this effect will decline over time. Further, a decrease in water availability could lead to a decrease in CH_4 emissions from wetlands. Changes in variables such as the areal extent of wetlands and the duration of the active period will determine whether there will be a change in the total CH_4 flux from a wetland. A lowering of the water table would probably not affect nitrous oxide emissions from bogs but could lead to an increase of emissions from fens, although emissions of nitrous oxide from wetlands tend to be low.

Conclusion: Changes in the source/sink relationship have already occurred in wetlands in some parts of the world. Both climate change and human (non-climate) factors are likely to further affect the biogeochemical functions of wetlands.

Wetland vegetation fixes CO_2 from the atmosphere and eventually is added to the top layers of the wetland soil as organic litter. Part of the organic litter is oxidized and emitted as CO_2, and some is accumulated as peat. Several investigations have shown that soil CO_2 efflux from peatlands is strongly related to temperature (Svensson *et al.*, 1975; Svensson, 1980; Glenn *et al.*, 1993; Crill, 1991), although Moore (1986) found a poor correlation between temperature and CO_2 emission rates. Since most of the CO_2 emitted is produced by the upper soil layers (Stewart and Wheatly, 1990), it mainly originates from organic material that has not yet become a part of the peat proper, known as the catotelm. Carbon litter reaching the soil may be either oxidized (emitted as CO_2) or accumulated. Thus, a change in CO_2 emissions will be directly correlated to the portion of organic matter transferred to the catotelm. Because the CH_4 formed will be accompanied by a nearly equal amount of CO_2 (see Gujer and Zehnder, 1978), this relation should hold for most peatland types.

According to one CO_2 efflux temperature-moisture regression model (Svensson, 1980) of the transfer rate of organic matter to the catotelm due to changes in temperature, CO_2 emissions should rise by 12% for each degree Celsius increase in average temperature, given the mean seasonal moisture level. Accordingly, a temperature increase of 1–5°C would result in a 10–60% decrease in the rate at which organic matter is transferred to the catotelm.

Peat accumulation has varied substantially over past millennia (see Malmer, 1992), which is reflected in the quality of peat as a substrate for decomposers. The degradation rate of deep peat is limited by substrate quality rather than by abiotic factors (Hogg *et al.*, 1992). Therefore, the decomposition rate in deep peat will be fairly constant and only marginally affected by changes in temperature. Such constancy would improve the usefulness of the model described above in predicting changes in peat accumulation in response to a temperature change. Changes in hydrology also will influence the accumulation rate of peat because the position of the water table regulates the extent of oxygen penetration into the peat profile. The effect of a lowered water table due to climate change can be compared to the effects noted after drainage of peatlands for forest production. Drainage results in an increased decomposition rate and elevated fluxes of CO_2 to the atmosphere (Silvola *et al.*, 1985; Silvola, 1986; Moore and Knowles, 1989): A 25-cm lowering of the water table gave rise to a twofold increase in CO_2 emissions from peat (Silvola *et al.*, 1985; Moore and Knowles, 1989). Depending on the type of peatland, this elevated flux may reduce carbon accumulation or even reverse the net flux of carbon to make the peatland a net source of atmospheric CO_2. Drained minerotrophic forested peatlands have been reported to respond in the latter way, whereas nutrient-poor peatlands may continue to accumulate carbon at a predrainage level (Laine *et al.*, 1994; see also Tamm, 1951, 1965). Average CO_2 evolution from northern peatlands has been estimated at about 200 $gC/m^2/yr$ (Silvola *et al.*, 1985; Moore 1986, 1989). Following drainage, an elevated CO_2 flow will decline over time (see Armentano and Menges, 1986) owing to substrate depletion as the more easily decomposable fractions of the peat become depleted. However, a drier climate will continue to "drain" the peat successively for a long period; the decline will occur later. To estimate the importance of this, it is assumed that the drainage response reported by Silvola *et al.* (1985) is linear with depth. The increase in CO_2 flows at subsequent drawdowns of 5 cm would then be 40 $gC/m^2/yr$ or another 20% per depth interval.

The scenarios for 2020 and 2050 for the areas of boreal and subarctic peatlands project a temperature increase of 1–2°C and a decrease in soil moisture. Based on this temperature change, it seems reasonable to expect a 25% decrease in the addition of organic matter to the catotelm. It is assumed that this effect would be amplified in response to a decrease in soil moisture. Thus, it is conceivable that the peat accumulation rate will decrease to half of the present rate or even less (i.e., <0.025–0.055 Gt C/yr). Boreal peatlands may even become net sources of atmospheric CO_2. In concluding his discussion of the response of northern wetlands to predicted climate change, Gorham (1991) gives the extreme example of a 1-cm breakdown of the boreal peat layers worldwide. This would result in 2 Gt C/yr, which corresponds to more than a third of the present release of carbon to the atmosphere via fossil fuel combustion. The response in net primary production in relation to climate change is more difficult to predict and may enhance or reduce the effects caused by the estimated changes in the degradation features of peatlands (see Malmer, 1992).

6.5.3.2. Climatic Controls on Methane Flux

The net emission of CH_4 from peatlands is dependent on how much CH_4 is formed in the anaerobic parts of the profile and the amount oxidized in the oxic zones. Because the position of the water table and the associated capillary fringe determine the thickness of the zones of production and oxidation of CH_4, the flux of CH_4 is intimately tied to the surface hydrology of the wetland—which in turn is controlled by climate (precipitation and evaporation) and the topographic and geologic setting (surface and subsurface water flow). A decrease in water availability in the peat can lead to a decrease in CH_4 emissions (Whalen *et al.*, 1996; Sundh *et al.*, 1994a, 1994b; Martikainen *et al.*, 1995; Roulet *et al.*, 1993). Deeper penetration of oxygen into the peat also will enhance the capacity of the peat to act as a CH_4-oxidizing filter for CH_4 diffusing from the CH_4-forming sources below. Changes in the direction or magnitude of any or all of the controlling variables discussed above will affect the CH_4 flux. A change in the total CH_4 flux from northern wetlands can be expected if the areal extent of wetlands changes, the duration of the active period changes, and/or the per-unit-area production or oxidation of CH_4 changes.

The relations among moisture content, temperature, and CH_4 flux in individual wetlands have received much attention (Bartlett *et al.*, 1992; Crill *et al.*, 1988; Dise *et al.*, 1992; Moore and Knowles, 1989; Moore and Dalva, 1993; Moore and Roulet, 1993; Svensson, 1976; Svensson and Rosswall, 1984). These relations have been used to estimate qualitatively the year-to-year variation in the flux and the possible direction of change based on changes in temperature and precipitation obtained in 2 x CO_2 scenarios (Table 6-3). Four different approaches have been used to address this issue: (1) correlation of the time series of CH_4 fluxes with the time series of temperature and moisture using interannual data sets; (2) direct observations of changes in CH_4 flux in manipulation experiments that simulate expected changes in wetlands due to climate change; (3) modeling of variability of CH_4 flux using existing climate records and regressions between temperature and CH_4 flux; and (4) modeling of thermal and hydrological regimes of wetlands in 2 x CO_2 climate scenarios and then modeling of change in CH_4 flux using regressions relating CH_4 flux to temperature and moisture in order to predict a change in flux. These studies have shown that the flux of CH_4 is moderately sensitive to changes in temperature and very sensitive to changes in moisture. Using these relative sensitivities as a guide, a qualitative assessment of CH_4 flux from northern wetlands according to six possible climate scenarios is made (Table 6-3). At present, it is not possible to obtain reliable quantitative estimates of the change in flux because the surface hydrology of general circulation models is too coarse to adequately represent the small changes in moisture regime that probably affect the CH_4 flux.

6.5.3.3. Effects on Nitrous Oxide Emissions

Emissions of N_2O from northern wetlands are low. *In situ* chamber measurements and laboratory experiments with intact peat cores have revealed emissions below 0.025 g N_2O-N/m²/yr (Urban *et al.*, 1988; Freeman *et al.*, 1993; Martikainen *et al.*, 1993). A lowering of the water table of bogs will not affect their N_2O emissions, whereas it could strongly increase emissions from fens. Annual emission rates in the range of 0.05–0.14 g N_2O-N/m²/yr have been reported for drained peat by Martikainen *et al.* (1993) and Freeman *et al.* (1993). The difference between bogs and fens can be explained partly by the fact that drained peat profiles of fens have the capacity to nitrify (Lång *et al.*, 1994). N_2O emissions from drained boreal fens are lower than those from drained agricultural organic soils but 10–100 times higher than the rates from coniferous forest soils (Martikainen *et al.*, 1993).

6.5.4. Case Study: Kalimantan

6.5.4.1. Background

Kalimantan is one of the largest islands (539,460 km²) in the Indonesian archipelago (see Box 6-3). The region has a humid tropical climate, with high temperatures and high precipitation. The peatlands of Kalimantan probably play a major role in determining local climate at the present time, although there is no substantial evidence to confirm this.

The largest wetland areas are found in low-lying alluvial plains and basins and flat-bottomed valleys. Most of the freshwater wetlands in the area are forested swamps, specifically either freshwater swamp forests or peat swamp forests (Silvius, 1989). The freshwater swamp forests are rich in epiphytes, rattans, and palms. They provide shelter for a range of rare and endangered species of wildlife, including numerous bird species. The peat swamp forests are a further developmental stage of the freshwater swamp forest. Deep peats are found in the central and western parts of the island (Sieffermann *et al.*, 1988, 1992; Rielly *et al.*, 1992). The peat swamp forests have a relatively high diversity of tree species, but the variety of wildlife tends to be poorer than in freshwater swamp forests (Whitten *et al.*, 1987). Because of the high acidity of the peats and the fact that they are difficult to drain, peat swamp forests are of limited agricultural value (Silvius, 1989). Both swamp types are important watershed areas capable of absorbing and storing excess water and reducing flooding in adjacent areas. They also are an important forestry resource, with many commercially valuable timber species.

The wetlands of Kalimantan currently are deteriorating through the loss of the natural ecosystem, including primary forest cover. Deforestation, drainage, and agriculture all limit the buffering capacity of developed wetlands, causing changes that are long-term and irreversible. Because much of the human settlement at the present time is located in the coastal zone, peat swamp forest on the deeper interior peats has not been subject to large-scale harvesting. These areas are used mainly for timber extraction rather than agriculture; hence, their vegetation cover remains relatively unmodified.

6.5.4.2. *Effects of Temperature Change*

The projected climate change for the region involves an increase in temperature ranging from 0–1.5°C. The effects of

Table 6-3: Potential changes in CH_4 flux from northern wetlands due to changes in the thermal and moisture regime (adapted with additions from Matthews, 1993).

Study Description and Location	Change in Thermal and/or Moisture Regime	Observed or Modeled Change in CH_4 Flux	Relative Sensitivity
Field observations of CH_4 flux and temperatures among tundra wetlands of the North Slope (Alaska) with differing moisture levels (1987–1989)[1]	$\Delta T = +4°C$ $\Delta T = +4°C$; wetter $\Delta T = +4°C$; drier	Four-fold increase Four- to five-fold increase Two-fold increase	Large positive sensitivity to temperature increase; small positive sensitivity to moisture change
Field observations of CH_4 flux from permanent tundra wetland sites (Alaska)[2]	4-year variation in temperature and moisture	4 times variation in flux: Flux increased with warmer, wetter conditions	Large positive sensitivity to both temperature and moisture changes
Field observations of CH_4 flux from drained boreal wetlands (Canada)[3]	$\Delta WT = -10$ cm $\Delta WT > -10$ cm	Elimination of CH_4 flux Wetland became small CH_4 sink	Large positive sensitivity to moisture change
Field observations of CH_4 flux from drained boreal wetlands (Finland)[4]	$\Delta WT = -4$ cm $\Delta WT = -20$ cm	Five-fold decrease Elimination of CH_4 flux	Large positive sensitivity to moisture change
Modeling study based on 20th-century historical summer temperature anomalies for five high-latitude wetland regions and a temperature/CH_4 flux regression model[5]	$\Delta T = \pm 2°C$	±15% variance in flux	Moderate sensitivity to temperature
Modeling study simulating change in summer temperature and water table for a northern fen (Canada) in a 2 x CO_2 scenario (+3°C, +1 mm/d P) and temperature/CH_4 flux, and water table/CH_4 flux regression models[6]	$\Delta T \approx +0.8°C$ $\Delta T = +2°C$ $\Delta WT = -14$ cm	+5% increase +15% increase -80% decrease	Moderate sensitivity to temperature; large sensitivity to moisture

Notes: ΔT = change in temperature; ΔWT = change in water table; P = precipitation.
[1]Livingston and Morrissey, 1991.
[2]Whalen and Reeburgh, 1992.
[3]Roulet *et al.*, 1993.
[4]Martikainen *et al.*, 1992.
[5]Harriss and Frolking, 1992.
[6]Roulet *et al.*, 1992.

Box 6-3. The Forested Swamps of Kalimantan: Effects on Habitat, Hydrology, and Carbon Cycling

Background: The wetlands of Kalimantan are found in low-lying alluvial plains and basins and flat-bottomed valleys. Most of the freshwater wetlands in the region are classified as forested swamps, specifically as either freshwater swamp forests or peat swamp forests. The freshwater swamp forests are important in providing shelter for rare and endangered species; both types are important as watersheds and habitats for valuable tree species. They also are carbon sinks but release carbon into the atmosphere when water declines. The Kalimantan wetlands currently are stressed by the loss of the natural ecosystem through deforestation, drainage, and agriculture. These activities limit the buffering capacity of developed wetlands, causing changes that tend to be long-term and irreversible. However, these inland wetlands have escaped some interference because most of the human settlements are located along the coastal zones.

Possible impacts: Increased temperatures are likely to result in a longer period of reduced rainfall because higher temperatures will cause evapotranspiration to exceed precipitation. This is likely to have deleterious effects on the vegetation and hydrology of these wetlands. Climate change also could enhance peat losses in the region that currently result from human interference. On the other hand, increased precipitation in the dry season is likely to be beneficial, as the lower water levels that are typical in this season lead to a net loss of carbon into the atmosphere and an increased risk of fire (one of the greatest threats to their functioning).

Conclusion: It is possible that some measures may be taken in this region in the near future to abate the detrimental impacts caused by human (non-climate) stresses on these wetlands. The extent to which adaptations will be sufficient to counteract changes imposed by a changing climate as well cannot be determined. However, human activities that reduce the resiliency of these wetlands, as well as planned development of previously undisturbed areas of swamp forest, will likely lead to considerably enhanced carbon transfer from the wetlands to the atmosphere, even without climate change.

higher temperature and longer dry periods combine to produce a longer period when evapotranspiration exceeds rainfall and effective rainfall is greatly reduced. This, linked to increasing human activity on peatlands—such as timber extraction, agricultural development, and construction work—could have serious consequences.

Much of the Kalimantan lowland area is subjected to a distinct dry season from July to September or October in which there are high water losses from wetlands as a result of direct evaporation and evapotranspiration. Thus, water levels drop and peat oxidation occurs, with a net loss of carbon to the atmosphere. The spread of fire is one of the greatest threats to the functioning of these wetlands. Peat fires occur frequently in the region, creating palls of smoke sufficiently heavy to close local airports. In 1983–84, fires destroyed 3.5 Mha of both dipterocarp and peat swamp forest in Kalimantan, resulting in a direct economic cost of $2–12 million and an incalculable ecological cost (Maltby, 1986). The risk of fires spreading from cultivated to forest areas increases during the dry season and would increase if the dry season were extended.

6.5.4.3. *Effects of Precipitation Change*

Estimated precipitation changes for the area range from -20% during winter to +40% during the summer. The higher "summer" (i.e., dry-season) values are beneficial to the peatlands because this is the time when they experience the greatest drawdown of the water table. A decrease of precipitation in the wet season could be significant if, as a result, the dry season is extended.

Large-scale removal of the forests and drainage of the underlying peats could prevent further peat formation. The high peats of Kalimantan already appear to be degrading (Sieffermann *et al.*, 1988) and losing carbon directly through oxidation to the atmosphere or indirectly in surface drainage waters, followed by oxidation of carbon compounds at a later stage. Climate change would most surely exacerbate this degradation, leading to peat losses in this region.

6.5.4.4. *Remediation Possibilities*

A forest-management project in Kalimantan currently being sponsored by the British Overseas Development Administration will include suggestions for the sustainable management of the peat swamp forests. The resulting guidelines should help preserve the forest cover on the deeper peats, particularly if extraction methods do not intensify. Indonesian authorities also are introducing stricter regulations and controls on unnatural fires resulting from illegal land clearance and settlement. However, in 1986–89, a feasibility study was carried out to investigate the potential of using deep peat to generate electricity.

The extent to which these potential management changes will be sufficient to counteract the effects of climate change cannot be determined. However, utilization of the forests on these peats and planned development of previously undisturbed areas will likely lead to considerably larger carbon transfer from wetlands to the atmosphere even without climate change.

6.5.5. Case Study: The Florida Everglades

6.5.5.1. Background

The Everglades is a 500,000-hectare freshwater peatland dominated by vast expanses of sedge and sawgrass, interspersed with shallow-water aquatic communities (sloughs), wet prairies, and tree islands (Loveless, 1959; Gunderson, 1994). Peat accumulation and the subsequent formation of the Everglades began approximately 5,000 years ago as sea-level rise slowed after an initial rapid rise during deglaciation (Gleason and Stone, 1994). As recently as a century ago, the Everglades encompassed more than 1,000,000 hectares, but drainage for agriculture and urban development has resulted in the loss of more than half of the ecosystem (Kushlan, 1989; Davis *et al.*, 1994). The remaining area has been dramatically altered by construction of impoundments, canals, levees, and water-control structures; the system is managed, primarily, as a water source (Light and Dineen, 1994). During the wet season (June–November), excess water from agricultural land and suburban areas is pumped into the Everglades; during the dry season (December–May), the Everglades serves as a water source (DeGrove, 1984). In addition, approximately 50% of the water from the Kissimmee River/Lake Okeechobee complex—the "headwaters" of the Everglades—is diverted by canals to the Atlantic Ocean and the Gulf of Mexico before recharging the wetland (Light and Dineen, 1994). Thus, the present-day Everglades is characterized by a general reduction in the hydroperiod (Fennema *et al.*, 1994; Stephens, 1984; SFWMD, 1992; Walters *et al.*, 1992).

Long-term rates of peat accretion in the Everglades average 0.8–2.0 mm/yr, based on ^{14}C dating of the basal peat (McDowell *et al.*, 1969) and ^{210}Pb dating of peat cores (Craft and Richardson, 1993). However, alterations of the natural hydroperiod and nutrient regimes in the Everglades have resulted in changes in the rate of peat accretion. Areas experiencing reduced hydrology (caused by overdrainage) exhibit lower rates of accretion (1.6–2.0 mm/yr) compared to areas of extended hydroperiod (2.8–3.2 mm/yr) (Craft and Richardson, 1993). Likewise, pollen analysis of peat cores indicates a decrease in the extent of wetland vegetation such as sawgrass and slough and a concurrent increase in terrestrial "weedy" species (ragweed and pigweed) since drainage activities were initiated (Bartow *et al.*, 1994). Thus, future changes in the Everglades ecosystem caused by global warming must be interpreted in the context of recent anthropogenic alterations of hydrology and nutrient regimes (see Box 6-4).

6.5.5.2. Effects of Sea-Level Rise

The most immediate effect of climate change will be accelerated sea-level rise, resulting in saltwater intrusion into the lower part of the glades from Florida Bay (Wanless *et al.*, 1994). Increased salinity would result in encroachment of salt-tolerant wetland communities such as mangroves and salt marshes. The areal extent of freshwater communities such as sawgrass, slough, and wet prairie will decrease, and the amount of organic carbon sequestered also will decrease. Another biogeochemical consequence of saltwater intrusion is a shift in anaerobic decomposition away from methanogenesis toward nitrate and sulfate reduction.

6.5.5.3. Effects of Temperature Change

Temperature is expected to increase from 0.5 to1.5°C, likely resulting in an increase in evapotranspiration—which may

Box 6-4. The Florida Everglades: Effects on Water Supply and Critical Habitats

Background: The Everglades is a freshwater peatland dominated by sedge and sawgrass, with sloughs, wet prairies, and tree islands. The Everglades is important as a habitat for wildlife, fish, and plant species and as a water source for the neighboring community. It is estimated that drainage for agriculture and urban development in the past century has resulted in a loss of more than half of the ecosystem, and the remaining wetlands have been altered by other construction and so forth.

Possible impacts: Sea-level rise is expected to be perhaps the most important variable that will affect the Everglades, causing saltwater intrusion that is likely to result in an encroachment of salt-tolerant wetland communities. This would decrease the areal extent of the freshwater wetlands, with some effects on anaerobic decomposition. The increased evapotranspiration expected in some seasons would exacerbate this saltwater intrusion. Increased temperature is likely to cause a northward migration of some introduced species but could be conducive for other species. Climate change also is expected to affect the hydrology of the wetlands, causing higher water levels in the winter and lower levels in the summer. This could result in the loss of critical habitats such as sawgrass and wet prairie communities, although these losses are likely to be offset by an increase in woody shrubs and trees.

Conclusion: Overall, the impacts that are projected as a result of climate change would adversely affect the end-users of the ecosystem: waterfowl, fish, and other wildlife; hunters, fishers, and tourists; and surrounding populations that rely upon the Everglades for freshwater resources. However, some action is currently underway to modify the water-control structure in an effort to restore the Everglades.

further exacerbate saltwater intrusion into the Everglades. Although more water will be lost to evapotranspiration, it is likely that oxidation and subsidence of the peat soils will not be dramatically affected because rising sea level will augment the groundwater table, particularly in the southern Everglades. Another consequence of increased temperature may be the northward migration of introduced species such as *Melaleuca quinquenervia*. *Melaleuca*, which has overtaken large areas of the southern Everglades, is seemingly kept in check by frost (Bodle *et al.*, 1994). However, increased temperatures caused by climate change might enable *Melaleuca* to colonize large areas of the northern Everglades.

6.5.5.4. *Effects of Precipitation Change*

Precipitation is projected to decrease during summer (0–20%) and increase during winter (0–20%). The winter months correspond to the dry season (November–May), when approximately 25% (10–15 inches) of the 50 to 60 inches of annual rainfall occurs (MacVicar and Lin, 1984). It is likely that an increase in rainfall during this season will reduce the rate of drawdown that normally occurs during this time. The reduction in summer rainfall in the wet season (May–October) should result in a lowering of the water table compared to current levels. These combined seasonal changes in rainfall should dampen the oscillations between the summer wet season and the winter dry season. As a result, water levels in the Everglades probably will be somewhat higher in the winter and somewhat lower in the summer than they are at present.

A dampening of the annual hydroperiod fluctuation may result in a decrease in the extent of sawgrass, the dominant plant community in the Everglades. Sawgrass communities are partly maintained by fire (Gunderson, 1994); increased rainfall during the dry season may reduce the frequency of fires—in particular, the severe fires that occur in the beginning of the wet season (May) that often burn large areas of the Everglades (Gunderson and Snyder, 1994). It is likely that wet prairie communities also will decrease in extent. These communities, which are important foraging habitat for wading birds (Hoffman *et al.*, 1994), frequently dry down during the spring (Goodrick, 1984). The dampening of the annual hydroperiod fluctuations caused by global warming will likely result in the loss of much of this critical habitat. The decline of sawgrass and wet prairie communities probably will be offset by an increase in woody shrubs and trees. These species are not generally fire-tolerant and often compete more effectively against emergents when water levels are stable.

6.5.5.5. *Socioeconomic Consequences*

It is likely that the greatest impact of climate change will be the loss of freshwater resources that sustain the burgeoning human population of south Florida, as well as the unique Everglades wetland. Competition for this diminishing resource will surely result in a no-win situation for humans and the Everglades under a scenario of global warming and rising sea level.

On a positive note, the U.S. Army Corps of Engineers, which oversees the water resources of south Florida, is evaluating modifications to the system of impoundments, canals, levees, and water-control structures in order to restore the Everglades (and other south Florida ecosystems) while providing for other water-related needs in the region (U.S. ACOE, 1994). This ambitious project, which could cost upward of $2 billion, is designed to increase the spatial extent of wetlands and restore the hydrology and water-quality conditions of the Everglades and other south Florida ecosystems.

6.6. Future Research Needs

Wetlands are highly valued in many areas. The lack of data to fully address their responses to climate change calls for several areas of research in the future:

- Site-specific responses are variable. There is a strong need for a local and regional coupling of climate-change predictions with known responses of specific wetlands, which would allow for modeling of the necessary interactive responses of the hydroperiod, temperature, and water availability at these scales. A network of different wetland sites in different regions of the globe should be established to form the base for such research.
- The feedback on climate by changes in trace-gas flows from wetlands, especially CO_2 and CH_4, upon a climate change calls for a strengthening of ongoing research in this field. This will aid in the judgments necessary for the introduction of adaptation and remediation measures on wetlands.
- The vast "grey" literature existing on different wetland subjects within the frames of local, regional, and country research reports should be examined to further substantiate site-specific responses by different wetlands, including changes in species composition, biogeochemistry, and socioeconomic consequences.

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9

Coastal Zones and Small Islands

LUITZEN BIJLSMA, THE NETHERLANDS

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CONTENTS

EXECUTIVE SUMMARY

Coastal zones and small islands are characterized by highly diverse ecosystems that are important as a source of food and as habitat for many species. They also support a variety of economic activities—which, in many places, has led to a high rate of population growth and economic development. Many studies indicate that overexploitation of resources, pollution, sediment starvation, and urbanization have:

- Led to a decrease in the resilience of coastal systems to cope with natural climate variability (High Confidence)
- Adversely affected the natural capability of these systems to adapt to changes in climate, sea level, and human activities (High Confidence)
- Led to increased hazard potential for coastal populations, infrastructure, and investment (High Confidence).

As demands on coastal resources continue to increase with a growing population and expanding economic activity, coastal systems continue to face increasing pressures, which often lead to the degradation of these systems. In many parts of the world, for example, coastal wetlands are presently disappearing due to human activities.

Since the IPCC First Assessment Report (1990) and its supplement (1992), the interrelationships between the impacts of climate change and human activities have become better understood. Although the potential impacts of climate change by itself may not always be the largest threat to *natural coastal systems*, in conjunction with other stresses they can become a serious issue for *coastal societies*, particularly in those places where the resilience of natural coastal systems has been reduced. Taking into account the potential impacts of climate change and associated sea-level rise can assist in making future development more sustainable. A proactive approach to enhance resilience and reduce vulnerability would be beneficial to coastal zones and small islands both from an environmental and from an economic perspective. It is also in line with the recommendations of the UN Conference on Environment and Development (UNCED) Agenda 21. Failure to act expeditiously could increase future costs, reduce future options, and lead to irreversible changes.

Important findings by Working Group I that are of relevance to coastal impact assessment include the following:

- Current estimates of global sea-level rise represent a rate that is two to five times higher than what has been experienced over the last 100 years (High Confidence).
- Locally and regionally, the rate, magnitude, and direction of sea-level changes will vary substantially due to changes in ocean conditions and vertical movements of the land (High Confidence).
- It is not possible to say if the intensity, frequency, or locations of cyclone occurrence would change in a warmer world (High Confidence).

Since 1990, there has been a large increase in research effort directed at understanding the biogeophysical effects of climate change and particularly sea-level rise on coastal zones and small islands. Studies have confirmed that low-lying deltaic and barrier coasts and low-elevation reef islands and coral atolls are especially sensitive to a rising sea level, as well as changes in rainfall, storm frequency, and intensity. Impacts could include inundation, flooding, erosion, and saline intrusion. However, it has also been shown that such responses will be highly variable among and within these areas; impacts are likely to be greatest where local environments are already under stress as a result of human activities.

Studies of natural systems have demonstrated, among other things, that:

- The coast is not a passive system but will respond dynamically to sea-level and climate changes (High Confidence).
- A range of coastal responses can be expected, depending on local circumstances and climatic conditions (High Confidence).
- In the past, estuaries and coastal wetlands could often cope with sea-level rise, although usually by migration landward. Human infrastructure, however, has diminished this possibility in many places (High Confidence).
- Survival of salt marshes and mangroves appears likely where the rate of sedimentation will approximate the rate of local sea-level rise (High Confidence).
- Generally, coral reefs have the capacity to keep pace with projected sea-level rise but may suffer from increases in seawater temperature (Medium Confidence).

The assessment of the latest scientific information regarding socioeconomic impacts of climate change on coastal zones and small islands is derived primarily from vulnerability assessments based on the IPCC Common Methodology. Since 1990, many national case studies have been completed, embracing examples of small islands, deltas, and continental shorelines from around the world. These studies mainly utilize a scenario of a 1-m rise in sea level and generally assume the present socioeconomic situation, with little or no consideration of coastal dynamics. There is concern that these studies understate nonmarket values and stress a protection-orientated response perspective. Despite these limitations, these studies provide some important insights into the socioeconomic implications of sea-level rise, including:

- Sea-level rise would have negative impacts on a number of sectors, including tourism, freshwater supply and quality, fisheries and aquaculture, agriculture, human settlements, financial services, and human health (High Confidence).
- Based on first-order estimates of population distribution, storm-surge probabilities, and existing levels of protection, more than 40 million people are estimated to experience flooding due to storm surge in an average year under present climate and sea-level conditions. Most of these people reside in the developing world. Ignoring possible adaptation and likely population growth, these numbers could roughly double or triple due to sea-level rise in the next century (Medium Confidence).
- Protection of many low-lying island states (e.g., the Marshall Islands, the Maldives) and nations with large deltaic areas (e.g., Bangladesh, Nigeria, Egypt, China) is likely to be very costly (High Confidence).
- Adaptation to sea-level rise and climate change will involve important tradeoffs, which could include environmental, economic, social, and cultural values (High Confidence).

Until recently, the assessment of possible response strategies focused mainly on protection. There is a need to identify better the full range of options within the adaptive response strategies: protect, accommodate, and (planned) retreat. Identifying the most appropriate options and their relative costs, and implementing these options while taking into account contemporary conditions as well as future problems such as climate change and sea-level rise, will be a great challenge in both developing and industrialized countries. It is envisaged that the most suitable range of options will vary among and within countries. An appropriate mechanism for coastal planning under these varying conditions is integrated coastal zone management. There is no single recipe for integrated coastal zone management; rather, it constitutes a portfolio of sociocultural dimensions and structural, legal, financial, economic, and institutional measures.

Integrated coastal zone management, which has already started in many coastal countries, is a continuous and evolutionary process that identifies and implements options to attain sustainable development and adaptation to climate change in coastal zones and small islands. Constraints that could hinder its successful implementation include, but are not limited to:

- Technology and human resources capability
- Financial limitations
- Cultural and social acceptability
- Political and legal frameworks.

Continued exchange of information and experience on the inclusion of climate change and sea-level rise within integrated coastal zone management at local, regional, and international levels would help to overcome some of these constraints. In addition, more research is required on the *process* of integrated coastal zone management to improve the understanding and modeling capability of the implications of climate change and sea-level rise on coastal zones and small islands, including biogeophysical effects, the local interaction of sea-level rise with other aspects of climate change, and more complete assessment of socioeconomic and cultural impacts.

9.1. Introduction

Coastal zones and small islands contain some of the world's most diverse and productive resources. They include extensive areas of complex and specialized ecosystems, such as mangroves, coral reefs, and seagrasses, which are highly sensitive to human intervention. These ecosystems are the source of a significant proportion of global food production. Moreover, they support a variety of economic activities, including fisheries and aquaculture, tourism, recreation, and transportation. In recent decades, many coastal areas have been heavily modified and intensively developed, which has significantly increased their vulnerability to natural coastal dynamics and the anticipated impacts of global climate change.

Many attempts have been made to define the "coastal zone" and its land and seaward boundaries. Some definitions are based on physiographic characteristics, such as the extent of tidal influence on the land or the geomorphology of the continental shelf; others simply use a fixed distance from the shoreline. In the case of small islands, the coastal zone could include the entire island. While the boundaries of the coastal zone may or may not coincide with political or administrative boundaries, they rarely coincide with those of areas from which demands on the resources of the coastal area are derived (Ehler, 1993).

Irrespective of how coastal zones are defined, the following characteristics, which are strongly interrelated, often make them distinctive from other areas:

- A high rate of dynamic changes in the natural environment
- A high biological productivity and diversity
- A high rate of human population growth and economic development
- A high rate of degradation of natural resources
- Exposure to natural hazards such as cyclones and severe storms
- The need for management regimes that address both terrestrial and marine issues.

The global importance of coastal zones and small islands in terms of both ecological and socioeconomic values is widely recognized. Many international organizations, including IPCC, have called for action to implement strategies toward better planning and management of coastal areas and resources to prevent them from being degraded and becoming progressively more vulnerable to the potential impacts of climate change and associated sea-level rise. The World Coast Conference, partly held under the auspices of IPCC, has supported the Framework Convention on Climate Change (UNCED, 1992a) and Agenda 21, Chapter 17 (UNCED, 1992b), requiring action on coastal zone management planning, among many other initiatives, by all signatories (WCC'93, 1993).

This chapter presents an assessment of the latest scientific information on the impacts of climate change on coastal zones and small islands and on strategies that countries may wish to apply in response to these impacts. It builds on the previous IPCC assessments carried out in 1990 and 1992 and on the work of the former Coastal Zone Management Subgroup (CZMS) of IPCC. The chapter concentrates on the scientific work completed since 1990, although earlier work is acknowledged where appropriate.

The structure of this chapter is schematically depicted in Figure 9-1. This figure also shows how this chapter relates to other chapters and Working Group reports of this IPCC Second Assessment Report. In Section 9.2, the functions and values of coastal zones and small islands are discussed. Special emphasis is put on the importance of maintaining the proper functioning of coastal systems with regard to sustainable development and their resilience to climate change. Section 9.3 then discusses the likely consequences of climate change on sea-level rise, sea-surface temperatures, and tropical cyclones in the context of coastal zones and small islands. On this basis, Section 9.4 addresses the effects of climate change on biogeophysical systems, and Section 9.5 examines the socioeconomic impacts. Section 9.6 considers response strategies to climate change and the need to integrate them with other coastal management activities. Finally, Section 9.7 identifies needs and opportunities for future research and monitoring that would help nations to respond more appropriately to the likely impacts of climate change on coastal zones and small islands.

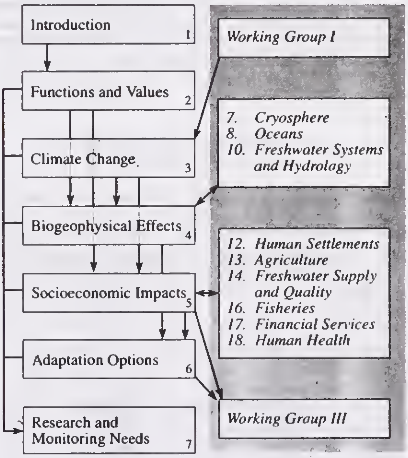


Figure 9-1: Structure of this chapter and interrelationships with other chapters and Working Group volumes of the IPCC Second Assessment Report.

9.2. Functions and Values of Coastal Zones and Small Islands

In large measure, human social and economic well-being depends directly or indirectly on the availability of environmental goods and services provided by marine and coastal systems. Coastal zones and small islands are characterized by highly diverse ecosystems, and a great number of functions are performed over a relatively small area. This concentration of functions, together with their spatial location, makes coastal zones and small islands highly attractive areas for people to live and work in. Coastal human populations in many countries have been growing at double the national rate due to migration to urban coastal centers; it is estimated that 50–70% of the global human population lives in the coastal zone, although there are great variations among countries. The existing rate of socioeconomic development in coastal zones also is unprecedented (WCC'93, 1994).

9.2.1. Functions and Values

The total economic value of coastal systems is more than simply the financial value of the coastal resources that they produce. It also includes their role in regulating the environment, their satisfaction of subsistence needs, and their satisfaction of human intellectual and emotional needs. De Groot (1992a) and Vellinga *et al.* (1994) have categorized the environmental functions performed by natural systems as regulation functions, user and production functions, and information functions. *Regulation functions* are crucial in safeguarding environmental quality. They include regulation of erosion and sedimentation patterns, regulation of the chemical composition of the atmosphere and oceans, flood prevention, waste assimilation, maintenance of migration and nursery habitats, and maintenance of biological diversity. Many natural and seminatural coastal systems thus play a fundamental part in the regulation of essential biospheric processes that contribute to the maintenance of a healthy environment and the long-term stability of the biosphere, including the climate system. *User and production functions* are essential in providing many living and nonliving resources that are utilized by human society. These functions include the provision of space and a suitable substrate for human habitation and a variety of socioeconomic activities. Important socioeconomic activities in coastal zones and small islands include tourism and recreation, exploitation of living and nonliving resources (e.g., fisheries and aquaculture; agriculture; extraction of water, oil, and gas), industry and commerce, infrastructure development (e.g., harbors, ports, bridges, roads, sea-defense works), and nature conservation. *Information functions* relate to the part that nature plays in meeting human intellectual and emotional needs. For example, coastal systems can be a source for cultural inspiration, but they also serve as a storehouse for genetic information. Also, scientific understanding of coastal processes and evolution depends on the geological and biological information that coastal systems contain.

Any coastal system can yield values related to the direct, indirect, and future use of the functions described above, as well as non-use, or intrinsic, values (Turner, 1988, 1991; Barbier, 1994). This is illustrated by Figure 9-2. Empirical

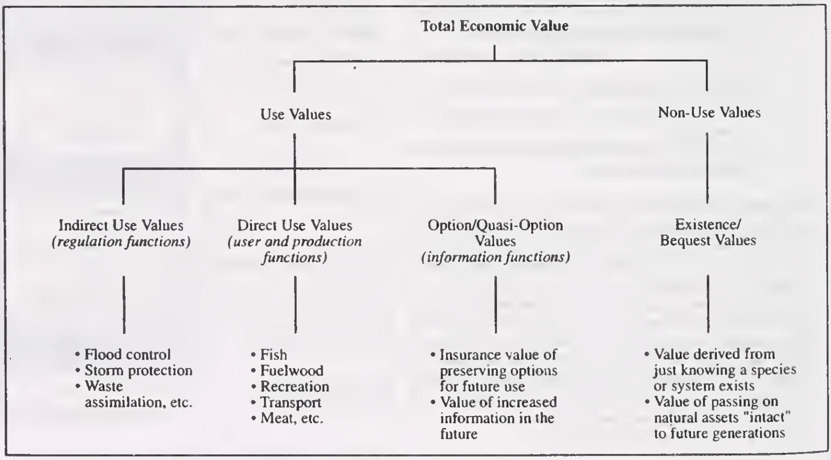


Figure 9-2: Values of coastal systems (adapted from Barbier, 1989).

studies confirm that coastal systems possess significant economic value, in terms of both use and non-use outputs. Mangrove forests, for example, have been shown to sustain more than 70 direct human activities, ranging from fuelwood collection to artisinal fisheries (Dixon, 1989). However, some uses preclude others, so some caution is necessary when the total economic value of such a system is estimated. This caution is also justified by the fact that many functions provide nonmarket goods and services and therefore do not carry appropriate market prices and value. Moreover, individuals and communities may find that nature has a value of its own, independent of human use or perception. They would therefore value nature purely because it exists and would feel a loss if it was damaged or destroyed.

Nonetheless, some studies are available that have produced estimates of the monetary value of coastal functions, using a variety of techniques. For example, recreation and amenity benefits provided by the Broadlands coastal wetland in England are estimated to be around $5 million per year (Bateman *et al.*, 1995). The storm buffering function of the Terrebonne coastal wetlands in Louisiana (United States) has been valued in terms of storm damage avoided. If the wetlands continue to recede at their present rate (3–4 m/yr), the present discounted value of increased expected property damage lies between $2.1–3.1 million (Constanza *et al.*, 1989). The total monetary value of all functions performed in the Ecuadorian Galápagos National Park amounts to $138 million per year (De Groot, 1992a).

9.2.2. *Sustainable Development*

In most coastal nations, a considerable part of gross national product (GNP) is derived from activities that are directly or indirectly connected with coastal zones. Therefore, maintaining the proper functioning of marine and coastal systems is of significant concern to a country's economy. In the shorter term, however, large financial benefits may be available at the expense of longer-term sustainability. Many coastal problems that are currently being encountered worldwide can be attributed to the unsustainable use and unrestricted development of coastal areas and resources. These problems include the accumulation of contaminants in coastal areas, erosion, and the rapid decline of habitats and natural resources. Great care must therefore be taken in planning to avoid overdevelopment and degrading or destroying the very environment that attracted coastal development in the first place.

Nonetheless, increasingly large areas of coasts and small islands have been managed with the aim of maximizing the financial "resource take" provided by the user and production functions performed by coastal systems. However, when one particular function is overexploited, this may not only result in the depletion of the resources that this function provides; it can also reduce the performance of other functions below their full potential. For example, when mangroves are logged and cleared in an unsustainable way, it can be at the expense of functions that enable fish to breed and be caught in the same area or that protect the coast from being eroded. The same applies when the capacity of regulation functions is exceeded—for example, when coastal waters are polluted beyond their waste-assimilative capacity. The maintenance of all functions at a sustainable level would provide higher economic returns over a longer period of time.

One can state that sustainable development in coastal zones and small islands is realized only when it enables the coastal system to self-organize—that is, to perform all its potential functions without adversely affecting other natural or human systems. Climate change could pose an additional threat to the full performance of these functions, compounding the pressures that present-day development activities already place on coastal zone capacities. Overexploitation of resources, pollution, sediment starvation, and urbanization may inhibit or destroy the working of functions that are essential to the provision of goods and services that are difficult to value in monetary terms, or in maintaining the resilience of coastal ecosystems to external stresses, such as climate change. For instance, one important regulation function of natural systems in coastal zones and small islands is the provision of a buffering capacity, protecting the land against the dynamics of the sea. As climate changes and sea level rises, this function will become even more important than it is today, preventing coastal areas from being eroded and inundated as much as they would without this natural protection. Nevertheless, although present-day human activities often result in large financial payoffs in the short term, they may also lead to environmental degradation. Such degradation results in the loss of functions, may increase coastal vulnerability to climate change, and has adverse economic effects on tourism, fishing, and other aspects of the coastal economy. In some cases, the long-term costs of these environmental disruptions may be greater than the long-term benefits of the human activity that caused them.

9.3. Aspects of Climate Change of Concern to Coastal Zones and Small Islands

Sea-level rise and possible changes in the frequency and/or intensity of extreme events, such as temperature and precipitation extremes, cyclones, and storm surges, constitute the components of climate change that are of most concern to coastal zones and small islands. Short-term extreme events are superimposed on long-term changes in CO_2 concentrations, climate, and sea level, and all aspects work in concert to bring about environmental change at regional and local levels. In order to understand fully their interactive effects on the coast, it is paramount to know how the means, variability, and extremes of the range of relevant climatic elements will change at local and regional scales. At such scales—with possibly a few exceptions—the predictive capability of models is currently very low, and knowledge about possible future changes in variability and extremes is meager. This section summarizes the main findings regarding sea-level and climate change that pertain to coastal zones (see the IPCC Working Group I volume for a full discussion).

9.3.1. Sea-Level Rise

9.3.1.1. Global Projections

In 1990, IPCC provided a best estimate and a range of uncertainty of sea-level rise, based on a "business-as-usual" projection of greenhouse-gas emissions for the period 1990–2100. It was estimated that sea level would, on average, rise by about 6 mm/yr, within a range of uncertainty of 3–10 mm/yr (Warrick and Oerlemans, 1990). Subsequent to IPCC90, projections of sea-level rise have been lower, largely as a result of downward revisions in the rate of global warming, which drives sea-level rise (see Section 9.3.2).

Present estimates of sea-level rise have been presented in Chapter 7, *Changes in Sea Level*, of the IPCC Working Group I volume. For a forcing scenario (IS92a) comparable to that of the IPCC 1990 assessment, it is estimated that sea level would, on average, rise by about 5 mm/yr, within a range of uncertainty of 2–9 mm/yr (see Figure 9-3). An important point to bear in mind is that the current best estimates represent a rate of sea-level rise that is about two to five times the rate experienced over the last 100 years (i.e., 1.0–2.5 mm/yr). The current projections of sea-level rise should therefore be of major concern in the context of coastal zones and small islands. Furthermore, model projections show that sea level will continue to rise beyond the year 2100 due to lags in climate response, even with assumed stabilization of global greenhouse-gas emissions (Wigley, 1995).

9.3.1.2. Regional Implications

One cannot assume that changes in sea level at regional and local levels will necessarily be the same as the global-average change, for two broad reasons. First, vertical land movements affect sea level. With respect to the coastal environment, it is relative sea level that is most important—that is, the level of the sea in relation to that of the land. Regionally and locally, vertical land movements can be quite large, even on the decadal time scale. For example, parts of Scandinavia experience uplift (and thus a relative sea-level decline) of about 1 m per century due to the continuing "glacial rebound" following the contraction of the large continental ice sheets at the end of the last Ice Age some 10,000 years ago (Aubrey and Emery, 1993). In contrast, the Mississippi delta is experiencing subsidence (a relative sea-level rise) of about 1 m per century due to consolidation by sediment loading and the diminished supply of additional sediments to the delta required for accretion (Day *et al.*, 1993; Boesch *et al.*, 1994). Locally, tectonic activity, groundwater pumping, and petroleum extraction can cause large and sometimes abrupt changes in relative sea level (Milliman *et al.*, 1989; Han *et al.*, 1995b). Subsidence of urban areas due to groundwater withdrawal has been a significant problem in many locations. In Japan, for example, 2.1 million people live in protected areas below high water due to this cause. Box 9-1 includes four examples of observed sea-level change. Emery and Aubrey (1991) have provided a comprehensive discussion of the

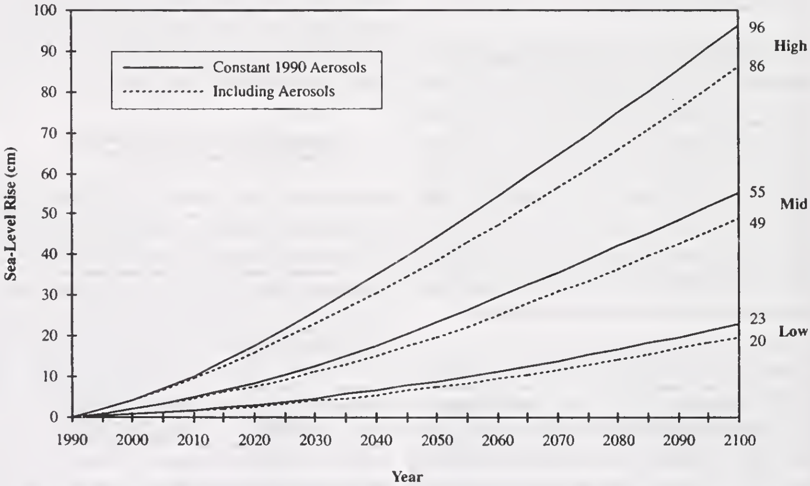


Figure 9-3: 1990–2100 sea-level rise for scenario IS92a (see Chapter 7, *Changes in Sea Level*, of the Working Group I volume).

Box 9-1. Four Examples of Observed Sea-Level Change

Figure 9-4 shows tide-gauge measurements of sea-level changes in Stockholm (Sweden), Fort Phrachula (Bangkok, Thailand), Honolulu (Hawaii, United States), and Nezugaseki (Japan). In a period of rising global sea levels, these four places show different trends in sea-level change due to their being situated in different geological settings. This illustrates the importance of local conditions on relative sea level. In Stockholm, glacial rebound is causing the land to rise out of the sea, resulting in a sea-level fall relative to the land of ~4 mm/yr. In Bangkok, human influence is apparent: Although over the period 1940–1994 relative sea-level rise averages 13.19 ± 0.73 mm/yr, two separate trends can be distinguished; the first, until about 1960, averages ~3 mm/yr, and the second, from 1960 onward, is ~20 mm/yr. The latter trend reflects the increased effort in groundwater pumping since 1960 (Emery and Aubrey, 1991). Nezugaseki shows the dramatic effects of an earthquake, which caused a 15-cm land submergence in 1964, along a coast generally dominated by emergence (Emery and Aubrey, 1991). The Honolulu record is believed to reflect a stable site and it is the only one of the four examples that approximates the global trend.

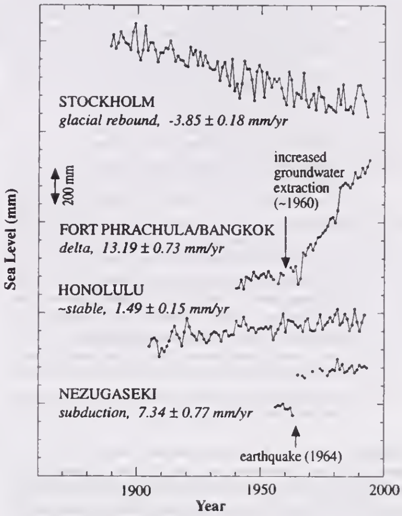


Figure 9-4: Relative sea-level records for Stockholm, Fort Phrachula (Bangkok), Honolulu, and Nezugaseki, indicating the geological settings and observed trends of the four sites (data provided by the Permanent Service for Mean Sea Level, Bidston).

effects of vertical land movements on relative sea level. In assessing coastal impacts, such vertical land movements must be considered in conjunction with climate-related changes in sea level.

Second, there are dynamic effects resulting from oceanic circulation, wind and pressure patterns, and ocean-water density that cause variations in the level of the sea surface with respect to the geoid—that is, the surface that the ocean would describe in the absence of currents, winds, and so forth. These variations have been observed to be on the order of 1 m for major current systems such as the Gulf Stream, Kuroshio, and the Antarctic Circumpolar Current (Pugh, 1987; Levitus, 1982). Climate change may affect ocean circulation, which can result in regional changes of this sea-surface "topography." Recent advances in ocean-atmosphere modeling offer some idea of the possible magnitude of such changes (e.g., Mikolajewicz *et al.*, 1990; Gregory, 1993; Murphy, 1992; Church *et al.*, 1991; Cubasch *et al.*, 1992). Model results show ranges of regional sea-level change that are on the order of two to three times the global-average change (see Box 8-2 in Chapter 8). However, it should be emphasized that confidence in coupled ocean-atmosphere model predictions of regional sea-level changes still must be considered low, as reliable regional scenarios of this effect are not yet available for impact analysis.

9.3.2. *Climate Changes*

One of the certainties regarding global climate change is that the *atmospheric concentration of carbon dioxide* (the major player among the greenhouse gases), now about 360 ppmv, has increased by about 29% over the preindustrial concentration and will continue to increase in the future, even if rather stringent policies on CO_2 emissions were adopted. Although controversial, there is some evidence that increased CO_2 would lead to significant increases in net primary productivity through enhanced photosynthesis (Melillo *et al.*, 1993), which could potentially have far-reaching implications for coastal vegetation and the coastal environment.

Recent projections of *global warming* (Mitchell and Gregory, 1992; Wigley and Raper, 1992; see also Chapter 6, *Climate Models—Projections of Future Climate*, of the IPCC Working Group I volume) are somewhat lower than those presented in IPCC90 (about 0.2°C per decade, as compared to 0.3°C per decade averaged over the next century). Nonetheless, the best-estimate projection still falls within a very large range of uncertainty. Thus, such projections are plausible scenarios of what could occur, not necessarily of what will occur. This caution should be applied even more emphatically to regional details of climate change as they are derived from general circulation models (GCMs). While refinements have been made since

IPCC90, the overall judgment is that confidence in the predicted patterns of climate change at spatial scales relevant to coastal zones and small islands must still be regarded as low (Gates *et al.*, 1992, 1990; Mitchell *et al.*, 1990; McGregor and Walsh, 1993). Nonetheless, there are some broad regional results that are consistently produced by equilibrium and transient GCM experiments that have relevance to the coastal zone. These results include (Mitchell *et al.*, 1990; Gates *et al.*, 1992):

- The mean surface air temperature increases more over land than over oceans (by about a factor of two), and at higher latitudes during winter. The climate of the coastal zone tends to be moderated by ocean temperature and will thus be strongly influenced by sea-surface temperature changes. Northern Hemisphere warming is greater than Southern Hemisphere warming because of the larger extent of land.
- In general, global models show increases in precipitation throughout the year in the high latitudes and during the winter in mid-latitudes. Most models show some increase in Asian monsoon rainfall.
- At scales relevant to coastal zones and small islands, predictions of changes in other climate elements, such as windiness, storminess or radiation, cannot yet be considered reliable.

Although changes in *sea-surface temperatures* (SSTs) are projected to be less than those on land, they are not necessarily less significant. As Edwards (1995) has pointed out, a 2°C change in SST in the tropical and subtropical oceans is considered to be anomalous, but is on the order of temperature changes associated with strong El Niño/Southern Oscillation (ENSO) events. In comparison, the projected change in mean sea-surface temperature for these regions is on the order of 1–2°C by the year 2100. Thus, by 2100, SSTs that are now considered anomalous could well be normal occurrences. Such warming would be unprecedented in the recent geological past.

Tropical cyclones (also known as hurricanes or typhoons, depending on region) affect vast coastal areas in tropical and subtropical countries. Tropical cyclones and associated storm surges can cause enormous loss of life and have devastating impacts on coastal ecosystems and morphology. It is therefore of critical importance to know how the frequency, magnitude, and areal occurrence of such storms will change in a warmer world, if at all. Unfortunately, the evidence from theoretical and numerical models and from observational data is, as yet, inconclusive. While current GCMs provide some indication of possible tropical cyclone formation, identifying "tropical disturbances" (e.g., see Broccoli and Manabe, 1990; Haarsma *et al.*, 1993), they cannot explicitly model such storms at the present grid-scale resolution (Mitchell *et al.*, 1990). However, recent work has been moving in this direction (e.g., Bengtsson *et al.*, 1994). Alternatively, theoretical storm models have been used to examine the maximum storm intensity in relation to SSTs (Emanuel, 1987) but cannot easily be extended to address questions of regional changes in tropical storm intensity or frequency under conditions of climate change (Schlesinger, 1993; Lighthill *et al.*, 1994).

At present, there is no evidence of any systematic shift in *storm tracks*. The tracks are governed by the location of cyclogenesis and prevailing meteorological conditions; thus far, there is no evidence of shift in the preferred locations of cyclogenesis. Empirical studies have found correlations between ENSO and the regional patterns of tropical cyclone activity (as well as the Southeast Asian monsoon, Atlantic hurricanes, Pacific precipitation patterns, and other phenomena) (Nicholls, 1984; Evans and Allan, 1992; see also Chapter 3, *Observed Climate Variability and Change*, of the IPCC Working Group I volume). Progress is being made on model simulations of the present features of ENSO-like events (e.g., Philander *et al.*, 1992), which could lead to a predictive capability for the future. Recent coupled-model simulations under enhanced CO_2 show a tendency toward ENSO-like patterns in the Pacific, with accompanying temperature and precipitation variability (see Chapter 6, *Climate Models—Projections of Future Climate*, of the IPCC Working Group I volume), but realistic simulations of ENSO are not yet possible. The behavior of ENSO is critical in understanding the future coastal effects of both climate change and sea-level rise in the Pacific region and elsewhere (Pittock and Flather, 1993; Pittock, 1993). In short, it is not yet possible to say whether either the intensity or frequency of tropical cyclones (or ENSO) would increase or the areas of occurrence would shift in a warmer world.

Despite the often repeated assertion that *climate variability* could increase in a warmer world, there is little evidence from climate models to support this notion (Gates *et al.*, 1992). However, Working Group I has identified at least one exception that has potentially large implications for coastal areas: Various GCMs consistently predict a higher frequency of convective precipitation in mid- to high-latitude regions of the world. This anticipated change may imply more intense local rainfall, with a decrease in the return period of extreme rainfall events (e.g., Gordon *et al.*, 1992). This could interact with sea-level rise to further increase the likelihood of flooding in low-lying coastal areas (Titus *et al.*, 1987; Nicholls *et al.*, 1995).

Without any change in variability, however, a change in mean value still implies a change in the frequency of *extreme events*. Because such events by definition are at the tails of the probability distribution, the change in return periods can be quite large relative to the change in mean value. In the absence of information about changes in variability, this simple concept has been employed to create scenarios of changes in extremes—for example, for temperature in Britain (Warrick and Barrow, 1991), rainfall in Australia (Pittock *et al.*, 1991), and storm surges in the United States (Stakhiv *et al.*, 1991). As has been pointed out at the beginning of this section, in most cases it is the combination of climate extremes—temperature, precipitation, winds, sea levels—and how they are affected by longer-term changes in climatic means that are especially important for considering the future effects of global warming on coastal zones and small islands. Yet little understanding of the possible interaction of different aspects of climate change in the coastal zone exists.

9.4. Biogeophysical Effects

In the 1990 IPCC Impacts Assessment, Tsyban *et al.* (1990) suggested that the most important aspects of climate change on the coastal zone would be the impact of sea-level rise on coastal residents and marine ecosystems. They argued that a rise in sea level would:

- Inundate and displace wetlands and lowlands
- Erode shorelines
- Exacerbate coastal storm flooding
- Increase the salinity of estuaries, threaten freshwater aquifers, and otherwise impair water quality
- Alter tidal ranges in rivers and bays
- Alter sediment depositional patterns
- Decrease the amount of light reaching water bottoms.

It was recognized then—and highlighted again in the IPCC 1992 supplement (Tsyban *et al.*, 1992) and at the meeting *The Rising Challenge of the Sea* (IPCC CZMS, 1992; O'Callahan, 1994)—that such effects would not be uniform around the world and that certain coastal environments would be especially at risk. These included tidal deltas and low-lying coastal plains, sandy beaches and barrier islands, coastal wetlands, estuaries and lagoons, mangroves, and coral reefs. Small islands became a major focus of concern because some of the more extreme predictions foreshadowed that low atoll and reef islands would completely disappear or become uninhabitable, with the total displacement of populations of several small island nations (Roy and Connell, 1991).

Many of the early studies on the effects of climate change emphasized sea-level rise and were based on a simple inundation model that vertically shifted the land-sea boundary landward by the amount of the projected global rise. However, it has become increasingly clear from recent studies that the geomorphological and ecological responses to a rising sea level will be complex and will also reflect a large number of other factors, including other aspects of climate change. No longer can effects be defined simply in terms of inundation of the sea upon the land, nor by just shifting the land-sea contour by an amount corresponding to the projected vertical increase in global sea level. Biogeophysical effects will vary greatly in different coastal zones around the world because coastal landforms and ecosystems are dynamic and both respond to and modify the variety of external and internal processes that affect them. Effects will depend not only on the local pattern of sea-level rise and climate change (as shown in Section 9.3) but also on the nature of the local coastal environment and on the human, ecological, and physical responsiveness of the particular coastal system being considered (J.R. French *et al.*, 1995).

Since the IPCC 1990 assessment, considerable progress has been made in understanding the effects of sea-level rise and climate change on coastal geomorphological and ecological systems. Studies have shifted from the use of simple, monothematic approaches to more complex yet pragmatic methods (Woodroffe, 1994). Three groups of approaches can be distinguished:

- Retrospective studies concerned with reconstructing past geomorphological and ecological responses to sea-level change in the Holocene, particularly during its rising stage
- Contemporary studies of geomorphological and ecological trends over the past several decades
- Mathematical and simulation modeling of coastal geomorphological and ecological systems using simplified sea-level rise scenarios and process assumptions.

In all three cases, emphasis has been on sea-level rise, with little consideration of other climate-change aspects, although sometimes increased seawater temperatures and storminess have been included. Invariably, global sea-level rise scenarios have been applied, irrespective of their appropriateness at the local or regional level. Further, several authors (e.g., Bird, 1993a; J.R. French *et al.*, 1995) have argued that it is not always appropriate to employ Holocene stratigraphical reconstructions as analogues for the future behavior of coastal systems, primarily because of the modern complications of human impacts that may now have an overriding effect on geomorphological and ecological responses.

In spite of the increased research effort, there is still no generally accepted global typology of coastal types relating to the potential effects of sea-level rise and climate change. There have been some attempts based on the resistance of the coast to environmental forces (e.g., Van der Weide, 1993), some based on both natural and socioeconomic features and processes (Pernetta and Milliman, 1995), and some through the development of a coastal vulnerability index that captures the different characteristics of a coastal region (e.g., Gornitz, 1991). The development of such a typology is clearly an area for substantial international research in the future. Moreover, the emphasis of recent studies on coastal types has been quite uneven. For instance, there has been little research on the potential effects of sea-level rise and climate change on high-latitude coasts, bold coasts, rocky shores, coastal cliffs, coarse clastic coasts, gravel barriers, coastal sand dunes, and seagrass beds. This lack of emphasis, however, does not necessarily imply that anticipated effects on these coastal types are less serious. Studies that show a strong correlation between sea-level rise and erosion of, for example, coastal cliffs, gravel barriers, and sand dunes include Griggs and Trenhaile (1994), Carter and Orford (1993), and Van der Meulen *et al.* (1991), respectively.

There are several comprehensive reviews on the biogeophysical effects of climate and sea-level change on coastal environments (e.g., Bird, 1993b; Oude Essink *et al.*, 1993; Wolff *et al.*, 1993). In addition to these general reviews there is a series of regional summaries covering a large area of the world—including the Mediterranean (Jeftic *et al.*, 1992), European coastal lowlands (Tooley and Jelgersma, 1992), Southeast Asia (Bird, 1993a), the South Pacific (Hay and Kaluwin, 1993), wider Caribbean (Maul, 1993), the Western Hemisphere

(Ehler, 1993), and the Eastern Hemisphere (McLean and Mimura, 1993)—as well as some edited volumes on specific themes, including geomorphic response (J.R. French *et al.*, 1995), coastal wetlands (Parkinson, 1994), and developing countries (Nicholls and Leatherman, 1995a). This section assesses first the biogeophysical effects of climate change on three distinct coastal geomorphic systems, then the effects on two important ecological systems, and finally the effects on coastal biodiversity.

9.4.1. Sedimentary Coasts, Sandy Beaches, Barriers, and Dunes

Open coasts, primarily made up of unconsolidated sands and gravels and exposed to wind and wave action, are common on all inhabited continents and islands of all sizes. About 20% of the world's coast is sandy and backed by beach ridges, dunes, or other sandy deposits. International studies reported by Bird (1985, 1993b) indicate that over the last 100 years about 70% of the world's sandy shorelines have been retreating; about 20–30% have been stable and less than 10% advancing. He has listed at least twenty possible reasons for the prevalence of erosion and has indicated that sea-level rise is only one possibility. Although Stive *et al.* (1990), Leatherman (1991), and others have recognized a causal relationship between erosion and sea-level rise, many attempts to correlate accelerated coastal erosion with global sea-level rise over the last 100 years have not been convincing because of the difficulties in excluding other factors, including human impacts. Analyses of erosional trends on sandy shorelines over the past several decades indicate a predominance of local rather than common explanations—suggesting that, if sea-level rise has been a contributor, its contribution may have been masked by other mechanisms.

Two other approaches have been used to gauge the effect of sea-level rise on sedimentary coasts. First, models have been used to predict beach-profile changes that will result from a rise in water level. Model studies have been reviewed by international expert committees such as the Scientific Committee on Oceanic Research (SCOR, 1991), as well as by individuals (e.g., Healy, 1991; Leatherman, 1991). The best-known model is that of Bruun (1962), who formulated a two-dimensional relationship between rising sea level and the rate of shoreline recession based on the concept of profile equilibrium, which has been the subject of much evaluation (e.g., Dubois, 1992). SCOR (1991) has noted that testing and application of the models for beach response to a long-term rise in sea level have been hampered by significant lag times of beach changes—amounting to months or years—and the importance of other elements of the sediment budget that produce shoreline erosion or accretion irrespective of any sea-level rise. Profile changes assumed by the models have been reasonably well-verified by laboratory and field studies, but the predictive equations are found to yield poor results when the effects of profile lag times and complete sediment budgets are not included in the analysis. One solution to these uncertainties is to determine a range of beach-recession scenarios rather than a single estimate—although SCOR (1991) has concluded that the status of models for the beach response to elevated water levels is far from satisfactory; predictions of the associated shoreline recession rates yield uncertain results; and there is clear need for substantial research efforts (field and laboratory) in this area. A new generation of shoreface-profile evolution models is presently being developed (e.g., Stive and De Vriend, 1995).

Second, morphostratigraphic studies, particularly of sandy barriers, have been undertaken, although frequently these studies predate the recent interest in attempting to predict future coastal response to climate change and sea-level rise. Nevertheless, sandy-barrier responses to rises in sea level in the Holocene can be used as historical analogues. Although transgressive sedimentary sequences, where coastal barriers migrate landward as a result of shoreface erosion and washover, are widespread in North America, Europe, and Australia, other responses to sea-level rise include ***in situ*** growth (the stationary barrier) and even seaward advance (the regressive sequence). As with other approaches, field-based evolutionary morphostratigraphic models do not yield a consistent response to sea-level rise. Rate of sediment supply and coastal configuration are just two of the other factors that influence how sandy shorelines will respond. In addition to field-based studies, some indication of the complex way that sand barriers have responded to post-glacial sea-level rise has been shown through computer-simulation techniques (Cowell and Thom, 1994; Roy *et al.*, 1994).

Collectively, all of these results suggest that with future sea-level rise there will be tendencies for currently eroding shorelines to erode further, stable shorelines to begin to erode, and accreting coasts to wane or stabilize. Locally, changes in coastal conditions and particularly sediment supply may modify these tendencies (Bird, 1985, 1993b).

9.4.2. Deltaic Coasts, Estuaries, and Lagoons

Deltas form where terrigenous sediment brought down to the coast by rivers accumulates more rapidly than can be removed by waves, tides, and currents. Although there is a wide spectrum of delta types around the world, all are the result of the interaction between fluvial and marine processes. Since ancient times, deltas have been of fundamental importance to civilizations due to the presence of highly productive agricultural lands, fisheries, and human settlement. Many modern delta regions, with their dense populations and intensive economic activities, are now in crisis because of past management practices such as dam, dyke, and canal construction and habitat destruction, which have led to problems such as enhanced subsidence and reduced accretion, salinity intrusion, water quality deterioration, and decreased biological production (Day *et al.*, 1993; Boesch *et al.*, 1994).

Deltaic coasts are particularly susceptible to any acceleration in the rate of sea-level rise (as well as storm frequency or intensity). As Baumann *et al.* (1984) have recognized, delta survival is a battle of sedimentation versus coastal submergence. Most deltas are subsiding under the weight of accumulating sediment, a process that often is enhanced by artificial groundwater withdrawal. Any global sea-level rise will exacerbate existing problems of local submergence. Bird (1993b) has argued that a rising sea level will have two major effects on low-lying deltaic areas: First, it is likely to cause extensive submergence, especially where there is little prospect of compensating sediment accretion. Second, progradation of most deltaic coastlines will be curbed, with erosion becoming more extensive and more rapid.

Similar conclusions have come from a host of case studies around the world, including those reported from Europe and the Mediterranean in Jeftic *et al.* (1992), Tooley and Jelgersma (1992), Poulos *et al.* (1994), and Woodroffe (1994); from the Americas in Day *et al.* (1993, 1994); and from Southeast Asia in McLean and Mimura (1993). While there appears to be general agreement among all of the studies on the implications of reduced sediment discharge, subsidence, and rising sea level, there have been few attempts to determine the relative vulnerability of deltaic regions or to model the effects of sea-level rise on deltas. Exceptions to the former include Ren's (1994) study of the Chinese coast, in which six variables (relief, land subsidence, shoreline displacement, storm surge, tidal range, and coastal defenses) have been used to evaluate risk classes of eight vulnerable areas. Exceptions to the latter include the conceptual model of general deltaic functioning developed by Day *et al.* (1994) and their two-state variable model, which simulates height in sea level and land elevation over time as a function of varying rates of sea-level rise, subsidence, and vertical accretion. Model results of the "date of immersion" (i.e., when sea level equals land elevation) have been produced for several sites in the Mississippi, Camargue, and Ebro deltas. Intradelta variations have been highlighted in the model results. In natural situations, such variations commonly result from variations in subsidence and/or changes in active and passive distributary positions across deltas, as demonstrated for the Nile (Stanley and Warne, 1993) and Rhine-Meuse (Tornqvist, 1993) deltas, respectively.

Studies on the physical response of tidal rivers and estuaries to predicted sea-level rise have covered two main areas—geomorphic changes and saltwater penetration—although the American Society of Civil Engineers (ASCE) Task Committee (1992) has indicated that several hydraulic processes such as tidal range, prism and currents, and sedimentation would also be modified. Bird (1993b) has suggested that estuaries will tend to widen and deepen. This may enhance their role as sediment sinks, causing greater erosion of the neighboring open coast (Stive *et al.*, 1990). However, Pethick (1993) has shown that along the southeast coast of Britain, where relative sea-level rise is already 4–5 mm/yr due to local subsidence, estuarine channels are becoming wider and shallower by local redistribution of sediment as the intertidal profile shifts both upward and shoreward. In some areas, these effects may be offset by increased catchment runoff, greater soil erosion, and increased sediment yield as a result of climate changes. However, as with deltas, critical factors will be relative sea-level change, including local subsidence (e.g., Belperio, 1993), and sediment availability (e.g., Chappell, 1990; Parkinson *et al.*, 1994). In macrotidal estuaries in Northern Australia, channel widening initiated by rising sea level will contribute sediment to the adjacent estuarine plains, which may offset the effect of flooding and lead to steady vertical accretion. One consequence of this would be to endanger backwater swamps and freshwater ecosystems on the estuarine plains (Chappell and Woodroffe, 1994).

The effects of sea-level rise on saltwater penetration in rivers and estuaries have recently been reviewed by Oude Essink *et al.* (1993) and Van Dam (1993), who have suggested that saline water will gradually extend further upstream in the future. More serious is the accelerated effect of saline water intruding into groundwater aquifers in deltaic regions and coastal plains. In these areas, the effect of sea-level rise can be exacerbated by the withdrawal of freshwater, which may result in either subsidence and/or replacement by seawater. Subsidence and landward migration of saltwater are already serious problems in many coastal deltaic areas around the world. Two examples are Myanmar (Aung, 1993) and China (Han *et al.*, 1995b).

9.4.3. Coral Atolls and Reef Islands

Coral atolls and reef islands appear especially susceptible to climate change and sea-level rise. Based on the sea-level rise scenarios of the 1980s and the application of simple models, Pernetta (1988) developed an index of island susceptibility for the South Pacific region and concluded that the most susceptible nations included those "composed entirely of atolls and raised coral islands, which will be devastated if projected rises occur," and consequently "such states may cease to contain habitable islands." Three related effects were envisaged: erosion of the coastline, inundation and increased flooding of low-lying areas, and seawater intrusion into the groundwater lens, which would cause reductions in island size, freeboard, and water quality, respectively.

Since that time, a series of vulnerability assessments of atolls and reef islands have been carried out. Studies include the atoll states and territories of Tuvalu, Kiribati, Tokelau, and the Marshall Islands in the Pacific and the Maldives and Cocos (Keeling) Islands in the Indian Ocean (Aalbersberg and Hay, 1993; Woodroffe and McLean, 1992; McLean and D'Aubert, 1993; Holthus *et al.*, 1992; Connell and Maata, 1992; Pernetta, 1992; McLean and Woodroffe, 1993). Generally, these studies have documented the likelihood of more complex and variable responses than initially suggested, recognizing that the balance between reef growth, island accumulation or destruction, and sea-level rise will be locally important. Differences in response can be further expected between islands within and beyond storm belts, between those composed primarily of sand and those of coral rubble, and between those that are or are not anchored to emergent rock platforms. The presence or absence of natural physical shore-protection structures in the form of beachrock or conglomerate outcrops and biotic protection in the form of mangrove or other strand vegetation will also result in different responses between islands.

It is not clear to what extent reef islands will erode or whether sediment from the adjacent reef or lagoon will contribute to the continued growth of islands. McLean and Woodroffe (1993) have envisaged at least three possible responses in the face of sea-level rise: the Bruun response, the equilibrium response, and continued growth, which would result in shoreline erosion, redistribution of sediment, and shoreline accretion, respectively. Each of these processes can be observed on many reef islands today, as well as in the stratigraphic record, suggesting that the factors identified above are significant determinants of island stability. Moreover, as Spencer (1995) has pointed out, coral-island responses to future sea-level rise will vary as a result of constraints on the development of modern reefs and the varying inherited topographies upon which future sea-level will be superimposed.

On small islands, the freshwater lens is an important resource and often is the primary source of potable water on atolls. Recent studies suggest that the first approximation of the response of the freshwater lens to sea-level rise (the Ghyben-Herzberg principle) is not appropriate on small coral islands. The layered-aquifer model—which, among other things, considers geological structure and distinguishes between Pleistocene and Holocene stratigraphic units—is considered more appropriate for assessing freshwater inventories on such islands. If recharge and island width remain constant or expand, freshwater lenses may actually increase in size with a rise in sea level because of the larger volume of freshwater that can be stored in the less-permeable upper (Holocene) aquifer (Buddemeier and Oberdorfer, 1990). On the other hand, if recharge or island width are reduced, a diminution in both freshwater quantity and quality can be expected. In many places, increasing demand and recharge contamination are likely to be more serious issues than freshwater inventory *per se*.

Although recent reviews on coral islands have emphasized their variability and resilience (e.g., Hopley, 1993; McLean and Woodroffe, 1993), such islands remain among the most sensitive environments to long-term climate change and sea-level rise, especially where these effects are superimposed on destructive short-term events such as hurricanes, damaging human activities, and declining environmental quality. In spite of a more optimistic outlook in recent years, Wilkinson and Buddemeier (1994) have maintained that coral-reef islands may be rendered uninhabitable by climate change, especially sea-level rise, and that will necessitate relocation of any remaining human populations (see also Section 9.5).

9.4.4. Coastal Wetlands

Coastal wetlands are frequently associated with deltas, tidal rivers, estuaries, and sheltered bays. Geomorphic and hydrologic changes resulting from sea-level rise will have important effects on these biological communities, as well as on unvegetated tidal flats. The survival of the latter is dependent very much on sediment supply from adjacent river catchments—which, if not provided, will result in substantial loss of such areas. Although Woodroffe (1993) has commented that research on coastal wetlands has concentrated upon reconstructing their development under conditions of sea-level rise during the Holocene, there also have been assessments of contemporary trends and processes and simulation modeling of environmental changes.

Historical studies of temperate salt marshes include those of Allen (1991) and Reed (1990), whereas Pethick (1993) and French (1993) have used current trends and numerical simulation, respectively. Pethick (1993) has shown that salt marshes in southeast England appear to be migrating inland along the estuary but that the natural changes are interrupted by the presence of flood embankments. The result is that loss of the seaward boundaries of these wetlands will continue without compensating landward migration—a process known as coastal squeeze in the United Kingdom. Wolff *et al.* (1993) have concluded that salt marshes have the ability to respond quickly to sea-level rise as long as sedimentation and internal biomass production processes keep pace and as long as the entire marsh can move to higher shore levels or further inland. Provided that it is not constrained by infrastructure, protection works, or other barriers, vertical accretion is likely to neutralize sea-level rise as long as sediment supply is sufficient and horizontal erosion is absent or can be compensated. If not, salt marshes will progressively decline and ultimately disappear. Pethick (1992) has also shown that salt marshes under stable sea level undergo cyclical changes to their seaward boundaries; infrequent high-magnitude storm events erode the edges, while intervening lower-magnitude events allow depositional recovery. An increase in the frequency of storm events as a response to sea-level rise would result in the replacement of such cyclical change by progressive erosion. The sensitivity of certain salt-marsh species to waterlogging and soil-chemical changes also could result in a change in species composition or the migration of vegetation zones (Reed, 1995).

Mangroves grow largely in tidal forests and are characterized by adaptations to unconsolidated, periodically inundated saline coastal habitats. They fringe about 25% of shorelines in the tropics and extend into the subtropics as far north as Bermuda and as far south as North Island, New Zealand. Studies on the effects of sea-level rise on tropical mangrove ecosystems have been primarily of historical nature (reviewed by Woodroffe, 1990; UNEP-UNESCO Task Team, 1993; Edwards, 1995). These studies have shown that extensive mangrove ecosystems became reestablished when sea level stabilized around 6,000 years BP. During the prior rise, mangroves probably survived as narrow coastal fringes, shifting landward with the migrating shoreline. Ellison and Stoddart (1991) and Ellison (1993) have indicated that mangroves in areas of low sediment input in both low-island and high-island settings appear to be unable to accrete vertically as fast as the projected rate of sea-level rise. However, recent evidence from the Florida Keys (Snedaker *et* *al.*, 1994) has shown that low-island mangroves may be resilient to rates of sea-level rise about twice those suggested as upper limits by Ellison and Stoddart (1991) from their study in Bermuda. It is also apparent that mangrove communities are more likely to survive in macrotidal, sediment-rich environments such as Northern Australia, where strong tidal currents redistribute sediment (Semeniuk, 1994; Woodroffe, 1995), than in microtidal sediment-starved environments such as around the Caribbean (Parkinson *et al.*, 1994).

If the rate of shoreline erosion increases, mangrove stands may tend to become compressed and suffer reductions in species diversity. On the other hand, extensive mangroves in deltaic settings with continuing large inputs of terrigenous sediment are likely to be more resilient to sea-level rise (Edwards, 1995). Thus, different responses can be envisaged in different mangrove settings. Additionally, certain species are likely to be more robust in the face of sea-level rise than others (Ellison and Stoddart, 1991; Aksornkaoe and Paphavasit, 1993).

It is now becoming increasingly clear, as Woodroffe (1993, 1994) and Edwards (1995) have observed, that coastal wetlands (marshes and mangroves) can undergo a number of responses to sea-level rise. Responses may be different in muddy, tide-dominated systems than in more organic systems, in areas of high or low tide range, and in areas of high or low sediment and freshwater input. Thus, the balance between accretion and submergence will be complex, and a range of morphological responses is likely for different coastal types and coastal settings. Although some marshes and mangroves may be under threat from sea-level rise over the next century, human impact has been the major threat up to the present and may be far more important locally than climate change in the long term (Bird, 1993a; WCC'93, 1994). In the case of mangroves, afforestation programs may be one way to compensate for natural or human-induced losses, although experiences in Bangladesh have indicated the difficulties in such a program (Saenger and Siddigi, 1993). There also is some evidence that coastal wetlands may experience loss due to short-term (decadal) acceleration in the rate of sea-level rise (Boesch *et al.*, 1994; Downs *et al.*, 1994).

Whereas mangroves are restricted to the intertidal zone, and salt marsh extends landward into supratidal areas, seagrasses extend subtidally to maximum depths of several tens of meters. Relatively little appears to have been published on the possible effects of climate change and sea-level rise on seagrasses (used here generically to include eelgrasses, turtlegrasses, etc.), although their biology and biogeography have been studied extensively (e.g., Larkum *et al.*, 1989; Mukai, 1993). Edwards (1995) has provided a brief but comprehensive analysis, noting the economic importance of seagrasses, and their ability to trap sediment, accrete vertically, stabilize unconsolidated sediment, slow water movement, and generally serve as natural coastal protection agents. Edwards (1995) has argued that intertidal and shallow seagrass beds (<5 m depth) are most likely to be affected by climate change, particularly by any sustained elevations in sea temperature or increases in freshwater runoff from land. However, the main threat to seagrass habitats is likely to come from increased anthropogenic disturbances, including dredging, overfishing, water pollution, and reclamation. In some parts of the world, seagrass beds are already severely threatened (Fortes, 1988), although elsewhere they have expanded due to eutrophication of estuarine waters.

9.4.5. Coral Reefs

Coral reefs are estimated to cover about 600,000 km^2 of the Earth's surface (Smith, 1978). They are dominated by calcifying organisms that are depositing about 0.6 to 0.9 Gt of calcium carbonate ($CaCO_3$) globally each year (Kinsey and Hopley, 1991). Intuitively, one would think that coral reefs—by precipitating $CaCO_3$ and sequestering carbon—would act as sinks for CO_2, but on the decade to century timescale this is not the case (Smith and Buddemeier, 1992). The calcification process actually generates CO_2 (Ware *et al.*, 1992), and over periods of decades reefs may contribute about 0.02 to 0.08 Gt C/yr as CO_2 to the atmosphere.

The effects of climate change on coral reefs, as well as nonclimatic anthropogenic disturbances, have recently been reviewed by Smith and Buddemeier (1992), Wilkinson and Buddemeier (1994) and Edwards (1995). The global climate-change effects of significance to coral reefs are likely to be increases in seawater temperature and sea-level rise; locally or regionally, changes in storm patterns and coastal currents, as well as changes in rainfall patterns, may have effects on coral communities—for example, through increases in sedimentation.

Coral reefs are particularly sensitive to increases in seawater temperature (Brown, 1987) and increased irradiance (Brown *et al.*, 1994). They respond to the combined effect of irradiance and temperature elevations by paling in color, or bleaching (Brown and Ogden, 1993). Corals do not generally bleach in response to rapid fluctuations in seawater temperature but rather to departures in temperature above their seasonal maximum. If the temperature elevation involves a substantial increase in seawater temperature (3–4°C) for an extended period (>6 months), considerable coral mortality can ensue (Brown and Suharsono, 1990). If, however, the temperature increase is only on the order of 1–2°C and for a limited period, bleached corals may recover but show reduced growth and impaired reproductive capabilities (Brown and Ogden, 1993).

Projected increases in seawater temperatures thus appear to be a major threat to coral reefs. In Indonesia, where severe bleaching took place as a result of seawater warming during an ENSO event in 1983, coral reefs have failed to show continued recovery beyond the initial recovery noted in 1988 (Brown and Suharsono, 1990). Such results have been mirrored in studies in the Galápagos and eastern Panama, where little recovery has been noted since major bleaching in 1982–1983. At sites in the East Pacific, reefs subsequently have shown rapid bioerosion from the destructive grazing activities of sea urchins, and destabilization of reef substrates is anticipated. Full community restoration probably will not occur for several hundred years (Glynn, 1993).

Reef accretion rates—calculated from community calcification rates, growth rates of calcifying organisms, and radiocarbon dating of cores through reefs—range from less than 1 mm/yr to a maximum slightly in excess of 10 mm/yr (Buddemeier and Smith, 1988; Hopley and Kinsey, 1988; Kinsey, 1991). A rate of 10 mm/yr is commonly taken as the consensus value for the maximum sustained vertical reef accretion rate (Buddemeier and Smith, 1988). The present best estimates for global sea-level rise over the next century (see Section 9.3) are well within the range of typical reef accretion rates. Even slowly accreting reef flats should, on average, be able to keep up with this rate of sea-level rise after a lag, provided that other factors such as increased seawater temperatures and damaging anthropogenic influences are not acting simultaneously (Edwards, 1995). Widespread warming of seawater, however, will clearly limit the accretion rates of coral reefs—as exemplified by the Panamanian reef, which before suffering 50% coral mortality as a result of sea-surface warming during an ENSO event was depositing about 10 tonnes $CaCO_3$/ha/yr and now is eroding at a rate of approximately 2.5 tonnes $CaCO_3$/yr, equivalent to vertical erosion of 6 mm/yr (Eakin, 1995).

Smith and Buddemeier (1992) have expected shifts in zonation and community structure associated with the interaction between wave-energy regime and sea level, although far too little is known about the physiological and physical constraints to reef growth (Spencer, 1995). Wilkinson and Buddemeier (1994) have shown that coral reefs have come through episodes of severe climate change in the past and have the necessary resilience to cope with current scenarios of climate change. However, coral reefs near land masses and near large population centers will come under greater human pressure in the future and are likely to be damaged beyond repair.

9.4.6. Coastal Biodiversity

Through the biogeophysical effects on coastal geomorphic and ecological systems described in Sections 9.4.1 through 9.4.5, climate change has the potential to significantly affect coastal biological diversity. It could cause changes in the population sizes and distributions of species, alter the species composition and geographical extent of habitats and ecosystems, and increase the rate of species extinction (Reid and Miller, 1989). Coral reefs have the highest biodiversity of any marine ecosystem, with enormous numbers of different species packed into small areas (Norris, 1993). Despite the known and potential value of reef communities and the threats to their health and vigor, the total biodiversity of coral reefs is not known, nor is the fraction of the diversity that is described versus undiscovered. Reaka-Kudla (1995) has estimated that there are about 91,000 described species of coral-reef taxa but argues that undocumented diversity is likely to be much higher. Nonetheless, coral-reef macrobiota represent about 4–5% of the described global biota, although they occupy less than 1% of the Earth's surface. Coral-reef biodiversity is centered around the archipelagos of the Philippines and Indonesia; diversity decreases away from this core. For example, the number of coral species in French Polynesia drops to less than 10% of that in the core area (Wilkinson and Buddemeier, 1994). Similar geographical variations in species richness occur in mangroves and tropical seagrasses (Woodroffe, 1990; Mukai, 1993).

In addition to marine systems such as coral reefs, coastal zones also comprise the adjacent terrestrial environments. Although scientists have long studied the interactions between marine and terrestrial systems and have seen the coastal zone as a discrete entity, it is poorly understood ecologically (Ray, 1991). Among all macroscopic organisms, there are 43 marine phyla and 28 terrestrial phyla; 90% of all known classes are marine (Reaka-Kudla, 1995). Ray (1991) has estimated that 80% of marine phyla occur in the coastal zone, which occupies only 8% of the Earth's surface, and argues that the marine portion of the coastal zone is the most biologically diverse realm on the planet. For example, of the 13,200 species of marine fish, almost 80% are coastal. Tropical coastal zones are particularly rich, with about 182,000 described species (Reaka-Kudla, 1995); they are about twice as rich as temperate coasts.

Coastal zones are sharply subdivided by gradients in geomorphic structure and habitat diversity; this enables them to perform many of the regulation functions and user and production functions outlined in Section 9.2.1. Ray (1991) has identified a nexus between physical processes and ecological pattern and diversity; he suggests that if global warming accelerates during the next few decades, the extent of coastal lagoons, marshes, and so forth will be affected and that these changes will strongly influence the fate of associated biota. In addition, intensive habitat modification on land and deterioration of coastal areas will clearly result in a decline of global biodiversity. Similarly, the capacity of species and ecosystems such as mangroves to shift their ranges and locations in response to climate change will be hindered by human land-use practices that have fragmented existing habitats. The establishment of nature reserves is seen as an option to arrest the decline of coastal biodiversity (Ray and Gregg, 1991; De Groot, 1992b).

9.5. Socioeconomic Impacts

Section 9.4 outlines how the coastal environment can be altered by climate change and sea-level rise; such alterations could have significant effects on functions and values in coastal zones and small islands. This section presents an overview of the related socioeconomic impacts and their evaluation, with an emphasis on the problems of sea-level rise. It highlights the particularly vulnerable situation of low-lying small islands and deltas. The emphasis on sea-level rise reflects a bias of existing studies. A discussion of the human activities in coastal zones that increase vulnerability to climate change also is included.

9.5.1. Pressures and Management Problems in Coastal Zones and Small Islands

During the twentieth century, urbanized coastal populations have been increasing because of the many economic opportunities and environmental amenities that coastal zones can provide. The need to protect and enhance the wealth-creation potential of coastal zones has led to widespread coastal construction and modification of natural coastal processes, resulting in losses of coastal habitats, changes in circulation and material flux, and reductions in biological productivity and biodiversity. These pressures are expected to increase substantially in the coming decades (WCC'93, 1994).

Of particular concern is the worldwide destruction and degradation of coral reefs, mangroves, sea grasses, and salt marshes—which, among other things, act as natural barriers against marine erosion processes. The natural response of salt marshes and mangroves to sea-level rise—an upward and landward migration of the intertidal profiles (see Section 9.4)—is inhibited by flood embankments and other human constructions. The result is that erosion of the seaward boundaries of these wetlands will continue without a compensating landward migration, leading to loss of wetland area. Deltaic processes also are being modified. In the United States, for example, the Mississippi River delta was roughly in a state of dynamic balance before the twentieth century, but since then human intervention in the form of large-scale engineering works, levees, dams, canals, and water diversions has effectively starved the wetlands of needed freshwater and sediments and radically altered wetland hydrology. Relative sea level is rising at a rate of up to 1 m per 100 years in this region; up to 100 km^2 of wetlands were lost each year during the 1970s, falling to 50 km^2/yr in the 1980s (Boesch *et al.*, 1994). In Bangladesh, flood defense systems and/or human activities in the Ganges-Bramaputra-Meghna river system may have affected runoff, sediment flow, and deposition rates, with detrimental effects on coastlines, fisheries, and the frequency and severity of inland flooding (Warrick and Rahman, 1992; see also Ives and Messerli, 1989). Small island states (many of which are low-lying) face particularly severe threats, and pollution and mining of coral will further serve to inhibit the capabilities of these countries to respond to sea-level rise.

Human interference in the dynamic processes that affect coastal zones is not restricted to activities within the coastal zone itself. Activities upstream in catchment areas may also play a part. For example, effluent discharging from sewage plants and industrial plants and agricultural runoff can lead to eutrophication, and water-resource schemes (e.g., dams and irrigation systems) can restrict the supply of water, sediment, and nutrients to coastal systems. Sewage and siltation are among the most significant causes of coral-reef and other natural coastal system degradation in the Philippines, Singapore, Malaysia, Indonesia, Sri Lanka, the Pacific islands, Hawaii, the Persian Gulf, the Caribbean, parts of the South American coast, and Cuba (Lundin and Linden, 1993).

The message is clear: Climate-related changes such as accelerated sea-level rise and possibly altered patterns of storm frequency and intensity represent potential *additional* stresses on systems that are already under intense and growing pressure. In addition, there are complex interrelationships and feedbacks between human and environmental driving forces and impacts on the one hand and climate-induced changes and effects on the other. These relationships require considerably more study (Turner *et al.*, 1995b).

9.5.2. Assessment of Impacts

Of direct relevance when analyzing socioeconomic impacts is the evaluation of the potential loss of environmental values. As discussed in Section 9.2, a coastal system can yield a number of different values related to the functions and services it provides. A range of methods is available to evaluate these (see Table 9-1).

Table 9-1: *Environmental evaluation methods showing—from left to right—increasing complexity and scale of analysis (adapted from Pearce and Turner, 1992).*

Least Complicated				*Most Complicated*
Financial Analysis	**Economic Cost-Benefit Analysis**	**Extended Cost-Benefit Analysis**	**Environmental Impact Assessment**	**Multi-Criteria Decision Methods**
• Financial profitability criterion • Private costs and revenues • Monetary valuation	• Economic efficiency criterion • Social costs and benefits • Monetary valuation	• Sustainable development principles • Economic efficiency and equity tradeoff environmental standards as constraints • Partial monetary valuation	• Quantification of a diverse set of effects on a common scale, but no evaluation	• Multiple decision criteria • Monetary and nonmonetary evaluation

The more comprehensive the technique, the greater the diversity of information that will be required and yielded to assist the appraisal of policy options from a societal perspective. Therefore, assessing the value of climate-change impacts is not a straightforward issue. More robust techniques are available for deriving use values than for non-use values. Moreover, monetary valuation is not always appropriate when cultural and heritage assets are threatened by climate change and sea-level rise. Small islands often are particularly threatened, including their distinct ways of life and possibly even their distinct cultures. The same applies to heritage and other culturally significant sites on the coast. The core project Land-Ocean Interactions in the Coastal Zone (LOICZ) of the International Geosphere-Biosphere Program (IGBP) (see also Sections 9.6.4 and 9.7) is currently preparing comprehensive guidelines for evaluating coastal functions and services.

Coastal zones and small islands support a range of socioeconomic sectoral activities that can be affected by climate change and sea-level rise. Most of these sectors are covered in separate chapters in this report. Table 9-2 reflects the results of these sectoral assessments as they pertain to direct impacts specifically related to climate change in coastal zones and small islands. The reader is referred to the chapters listed in the table for more detailed discussions of the impacts and vulnerability of each sector.

Tourism also is of great importance to coastal zones and small islands, although it is not covered as a separate sector in this report. Tourism helps to support the economies of many coastal countries (Miller and Auyong, 1991). For many small islands in particular, tourism is the largest contributor to the country's GNP. Coastal tourism can be affected by climate change directly through coastal erosion and changes in weather patterns (e.g., storminess, precipitation, cloud cover). Indirect effects, however, may be just as important. Adverse impacts on freshwater supply and quality, human settlements, and human health will severely affect tourism, as will overdevelopment leading to environmental degradation.

Many efforts have been made in the last few years to assess the implications of climate change and associated sea-level rise on the coastal zone. As part of these efforts, the former Coastal Zone Management Subgroup of IPCC has published a methodology for assessing the vulnerability of coastal areas to sea-level rise (IPCC CZMS, 1991). The framework, called the Common Methodology, has been widely applied as the basis of vulnerability assessment studies. These studies have aimed to identify populations and resources at risk and the costs and feasibility of possible responses to adverse impacts. The vulnerability of many more coastal countries to sea-level rise has been reviewed using other approaches. Examples of assessments of the possible impacts and responses to sea-level rise and climate change can be found in Tobor and Ibe (1990), Parry *et al.* (1992), Bijlsma *et al.* (1993), Warrick *et al.* (1993), Ehler (1993), McLean and Mimura (1993), Qureshi and Hobbie (1994), O'Callahan (1994), WCC'93 (1995), and Nicholls and Leatherman (1995a). A series of studies on Pacific islands has been conducted by the South Pacific Regional Environment Programme, including Holthus *et al.* (1992), Aalbersberg and Hay (1993), McLean and D'Aubert (1993), and Nunn *et al.* (1994a, 1994b).

This section summarizes a number of these vulnerability case studies, with an emphasis on the strengths and weaknesses of those conducted using the Common Methodology or similar approaches.

9.5.2.1. Vulnerability Assessment and the IPCC Common Methodology

Vulnerability to impacts is a multidimensional concept, encompassing biogeophysical, socioeconomic, and political factors. The Common Methodology defines vulnerability as "the degree of incapability to cope with the consequences of climate change and accelerated sea-level rise" (IPCC CZMS, 1991). Therefore, analysis of the vulnerability of a coastal area or small island to climate change includes some notion of its *susceptibility* to the biogeophysical effects of climate change and sea-level rise (see Section 9.4), as well as of its natural *resilience*—which is greatly influenced by past, current, and future population and settlement patterns and rates of socioeconomic change. Susceptibility and resilience together determine the natural system's *sensitivity* to anticipated changes. Socioeconomic *vulnerability* is further determined by a country's technical, institutional, economic, and cultural capabilities to cope with or manage the

Table 9-2: *Qualitative synthesis of direct impacts of climate change and sea-level rise on a number of sectors in coastal zones and small islands, based on other chapters in this volume. Chapter numbers are in parentheses.*

	Climate-Related Events				
Impact Categories	Coastal Erosion	Flooding/ Inundation	Saltwater Intrusion	Sedimentation Changes	Storminess
Human Settlements (12)	✓	✓			✓
Agriculture (13)		✓	✓		✓
Freshwater Supply and Quality (14)		✓	✓		
Fisheries (16)	✓	✓	✓	✓	✓
Financial Services (17)	✓	✓			✓
Human Health (18)		✓			✓

anticipated biogeophysical effects and their consequent socioeconomic impacts (Turner *et al.*, 1995a).

The IPCC Common Methodology has aimed to identify "*the types of problems that a country will have to face and, if necessary, the types of assistance that are most needed to overcome these problems.*" Assessments are to "*serve as preparatory studies, identifying priority regions and priority sectors and to provide a first reconnaissance and screening of possible measures*" (IPCC CZMS, 1991). Three boundary conditions and scenarios have been specified in the methodology: the impacts on the natural coastal systems, the impacts on socioeconomic developments, and the implications of possible response strategies for adaptation. The methodology includes consideration of the reference (or present) situation and a rise in sea level of 30 cm to 1 m by the year 2100. These scenarios approximate the low and high estimates of the 1990 IPCC Scientific Assessment. It considers socioeconomic developments by extrapolating 30 years from the present situation. The Common Methodology recommends considering a full range of adaptation options, including at least the extreme options of complete retreat and total protection. To simplify analysis, the method does not consider coastal evolution other than that caused by climate change, nor does it assess the effects of progressive adaptation at the local scale, such as the raising of dikes.

The Common Methodology has helped to focus the attention of many coastal nations on climate change and has contributed to long-term thinking about the coastal zone. On the other hand, a number of problems have been raised concerning the Common Methodology through the experiences of vulnerability assessment case studies (WCC'93, 1994):

- Many case studies have faced a shortage of accurate and complete data necessary for impact analysis. In particular, it often has proven difficult to determine accurately the impact zone in many countries due to the lack of basic data, such as the coastal topography.
- Many studies have found the use of a single global scenario of sea-level rise (1 m by 2100) inappropriate to their respective areas, often due to the lack of more detailed data on coastal elevations; most studies have ignored the spatial distribution of relative sea-level rise and other coastal implications of climate change, largely due to a lack of regional climate scenarios. Future vulnerability assessment would be greatly improved by the availability of regional scenarios for climate change and sea-level rise, including reference, low, and high scenarios.
- Although the Common Methodology has encouraged researchers to take into account the biogeophysical response of the coastal system to sea-level rise, lack of data and models for describing local coastal processes and responses have hindered detailed, quantitative impact assessment. Many case studies have carried out a simple first-order assessment by horizontally shifting the coastline landward by an amount corresponding with the sea-level rise scenario.
- While vulnerability profiles have yielded some useful relative guidance on potential impacts, the Common Methodology has been less effective in assessing the wide range of technical, institutional, economic, and cultural elements present in different localities.
- There has been concern that the methodology stresses a protection-orientated response, rather than considering a full range of adaptation options.
- Market-evaluation assessment frameworks have proved inappropriate in many subsistence economies and traditional land-tenure systems. More attention should be paid to broader socioeconomic evaluation techniques, which include traditional, aesthetic, and cultural values (see Box 9-2).

9.5.2.2. *Vulnerability Assessment Case Studies*

At least 23 country case studies have produced quantitative results that can be interpreted in terms of the IPCC Common

Box 9-2. Cultural Impacts and Alternative Assessments

Conventional impact evaluation techniques and indicators, such as GNP and population at loss, protection costs, and cost-benefit analysis, reflect only one (largely Western) approach for assessing potential damages from climate-related events. This has led to the development of alternative methodologies that seek to assess changes in culture, community, and habitat. In a study of coastal vulnerability and resilience to sea-level rise and climate change, Fiji is considered (Nunn *et al.*, 1994a). The methodology (Yamada *et al.*, 1995) computes a Sustainable Capacity Index based on the sum of ratings of vulnerability and resilience for many categories of cultural, social, agricultural, and industrial impacts at the local, regional, and national levels. Areas with higher concentrations of assets are judged to be more vulnerable, whereas areas with diversity and flexibility in the system—whether natural or managerial—tend to be viewed as more resilient in this analysis. The study has evaluated potential impacts to subsistence economies according to the view that communities in which people feed and clothe themselves with little cash exchange are more vulnerable but that subsistence economies in which staples can be replaced with other crops tend to be more resilient. In addition, cultural sites have been ranked according to the level of national interest in their preservation. The study concludes that subsistence economies and cultural assets are more vulnerable in Fiji and that conventional analyses of relatively high-lying islands such as Fiji would tend to underestimate the potential vulnerability of these areas, given that most people live in the low-lying coastal plain and the majority of cash and subsistence economic activities take place in the low-lying areas.

Methodology. Some results are summarized in Table 9-3, and these show considerable variation in possible impacts from country to country, reflecting that certain settings are more vulnerable than others. This conclusion is widely supported by all of the country studies that are available. Small islands, deltaic settings, and coastal ecosystems appear particularly vulnerable. In addition, developed sandy shores may be vulnerable because of the large investment and significant sand resources required to maintain beaches and protect adjoining infrastructure in the face of sea-level rise (Nicholls and Leatherman, 1995a).

Several caveats are in order so that the following impact estimates can be put into proper perspective (following Section 9.5.2.1). First, the impacts presented assume a 1-m rise in sea level by 2100—which is the high estimate of the IPCC90 business-as-usual sea-level rise scenario—and no other climate change. The latest scientific information, however, suggests a lower global mean sea-level rise (see Section 9.3.1.1). For a number of nations, the impacts of a 50-cm or smaller rise have been examined, including Argentina (Dennis *et al.*, 1995a), parts of north China (Han *et al.*, 1993), Japan (Mimura *et al.*, 1994), Nigeria (G.T. French *et al.*, 1995), Senegal (Dennis *et*

***Table 9-3:** Synthesized results of country case studies. Results are for existing development and a 1-m rise in sea level. People affected, capital value at loss, land at loss, and wetland at loss assume no measures (i.e., no human response), whereas adaptation assumes protection except in areas with low population density. All costs have been adjusted to 1990 US$ (adapted from Nicholls, 1995).*

	People Affected		Capital Value at Loss		Land at Loss		Wetland at Loss	Adaptation/ Protection Costs	
Country/Source	# people (1000s)	% Total	Million US$[1]	% GNP	km^2	% Total	km^2	Million US$[1]	% GNP
Antigua[2] (Cambers, 1994)	38	50	–	–	5	1.0	3	71	0.32
Argentina (Dennis *et al.*, 1995a)	–	–	>5000[7]	>5	3400	0.1	1100	>1800	>0.02
Bangladesh (Huq *et al.*, 1995; Bangladesh Government, 1993)	71000	60	–	–	25000	17.5	5800	>1000[9]	>0.06
Belize (Pernetta and Elder, 1993)	70	35	–	–	1900	8.4	–	–	–
Benin[3] (Adam, 1995)	1350	25	118	12	230	0.2	85	>400[10]	>0.41
China (Bilan, 1993; Han *et al.*, 1995a)	72000	7	–	–	35000	–	–	–	–
Egypt (Delft Hydraulics *et al.*, 1992)	4700	9	59000	204	5800	1.0	–	13100[11]	0.45
Guyana (Kahn and Sturm, 1993)	600	80	4000	1115	2400	1.1	500	200	0.26
India (Pachauri, 1994)	7100[6]	1	–	–	5800	0.4	–	–	–
Japan (Mimura *et al.*, 1993)	15400	15	849000	72	2300	0.6	–	>156000	>0.12
Kiribati[2] (Woodroffe and McLean, 1992)	9	100	2	8	4	12.5	–	3	0.10
Malaysia (Midun and Lee, 1995)	–	–	–	–	7000	2.1	6000	–	–
Marshall Islands[2] (Holthus *et al.*, 1992)	20	100	160	324	9	80	–	>360	>7.04
Mauritius[4] (Jogoo, 1994)	3	<1	–	–	5	0.3	–	–	–
The Netherlands (Peerbolte *et al.*, 1991)	10000	67	186000	69	2165	5.9	642	12300	0.05
Nigeria (G.T. French *et al.*, 1995)	3200[6]	4	17000[7]	52	18600	2.0	16000	>1400	>0.04
Poland (Pluijm *et al.*, 1992)	240	1	22000	24	1700	0.5	36	1400	0.02
Senegal (Dennis *et al.*, 1995b)	110[6]	>1	>500[7]	>12	6100	3.1	6000	>1000	>0.21
St. Kitts–Nevis[2] (Cambers, 1994)	–	–	–	–	1	1.4	1	50	2.65
Tonga[2] (Fifita *et al.*, 1994)	30	47	–	–	7	2.9	–	–	–
United States (Titus *et al.*, 1991)	–	–	–	–	31600[8]	0.3	17000	>156000	>0.03
Uruguay (Volonté and Nicholls, 1995)[5]	13[6]	<1	1700[7]	26	96	0.1	23	>1000	>0.12
Venezuela (Volonté and Arismendi, 1995)	56[6]	<1	330[7]	1	5700	0.6	5600	>1600	>0.03

[1]Costs have been adjusted to reflect 1990 US$.
[2]Minimum estimates—incomplete national coverage.
[3]Precise year for financial values not given—assumed to be 1992.
[4]Results are linearly interpolated from results for a 2-m sea-level rise scenario.
[5]See also review in Nicholls and Leatherman (1995a).
[6]Minimum estimates—number reflects estimated people displaced.
[7]Minimum estimates—capital value at loss does not include ports.
[8]Best estimate is that 20,000 km^2 of dry land are lost, but about 5,400 km^2 are converted to coastal wetlands.
[9]Adaptation only provides protection against a 1-in-20 year event.
[10]Adaptation costs are linearly extrapolated from a 0.5-m sea-level rise scenario.
[11]Adaptation costs include 30-year development scenarios.

al., 1995b), parts of the United Kingdom (Turner *et al.*, 1995a), the United States (Titus *et al.*, 1991), Uruguay (Volonté and Nicholls, 1995), and Venezuela (Volonté and Arismendi, 1995). Second, all of the country studies have assumed that the socioeconomic situation is constant until 2100. This is unrealistic and ignores the rapid coastal development that is occurring with little regard for existing problems, let alone tomorrow's (WCC'93, 1994). However, the mere threat of extensive loss of land and other assets may stimulate macroeconomic effects within national economies. Some assets may be relocated and others may be adapted to reduce the damage implications of climate change. On the other hand, the damage-cost estimates may represent underestimates because they neglect some nonmarket asset values and factors such as the cost of resettlement of coastal populations that cannot be easily protected. Finally, it has been assumed that the rise in sea level will be a slow, gradual process, which may not be the case for all regions. Scientific uncertainties are compounded by the socioeconomic adaptation uncertainties referred to above and by the fact that economic cost estimates are very sensitive to changes in discount rates.

Despite these limitations, these studies have offered some important insights into potential impacts and possible responses to climate change and sea-level rise. Many of the vulnerability assessments emphasize the severe nature of existing coastal problems such as beach erosion, waterlogging, and pollution (e.g., El-Raey *et al.*, 1995; Han *et al.*, 1995b). For many small islands, population pressure and urbanization, coastal pollution, and overexploitation of resources already are critical problems. For deltas and estuaries, changes in sediment supply and distribution are often already causing significant changes in the coastal zone. This reinforces the message that climate change will act on coastal systems that are already under stress.

In addition to accelerated sea-level rise, there is widespread concern about the coastal implications of other aspects of climate change such as changing rainfall and runoff in the catchment area, as well as the effects of changes in storminess and storm surges (e.g., Warrick *et al.*, 1993; McLean and Mimura, 1993). One quantitative vulnerability assessment study exists; it shows that in The Netherlands the costs of avoiding damage related to an adverse 10% change in the direction and intensity of storms may be worse than those of a 60-cm rise in sea level (Peerbolte *et al.*, 1991). This storm-change scenario is arbitrary, but shows that concern is justified and that there is a need for more widespread analysis.

All of the 23 national case studies shown in Table 9-3 project land loss as the sum of dry-land and wetland loss, assuming no protective measures are taken. The estimated losses range from 0.05% of the national land area in Uruguay (Volonté and Nicholls, 1995) to more than 12% of Tarawa, Kiribati (Woodroffe and McLean, 1992); more than 17% of Bangladesh (Huq *et al.*, 1995); and 80% of Majuro atoll, Marshall Islands (Holthus *et al.*, 1992). From fifteen case studies, 63,000 km^2 of wetlands are estimated to be lost. Most of these assessments are based on first-order analyses, and key parameters such as limiting vertical accretion rates and potential for wetland migration often are poorly defined (Nicholls, 1995). The study of the United States has considered wetland migration, estimating that a 50-cm rise in sea level would erode or inundate 38% to 61% of existing coastal wetlands. Assuming that dikes or bulkheads were not built to impede inland migration, new wetland formation on formerly upland areas would reduce the total loss to 17% to 43% (Titus *et al.*, 1991). Therefore, wetland migration is not projected to compensate for losses, even under the most ideal circumstances. Many studies, however, have found that direct human reclamation of wetlands for a range of purposes at present is a much bigger threat than sea-level rise (Nicholls and Leatherman, 1995a).

Fifteen case studies have provided estimates of undiscounted capital value potentially at loss, assuming no protection. Nearly half of the studies have concluded that capital value at loss could exceed 50% of present GNP, illustrating the concentration of infrastructure and economic activity in the coastal zones of many of the countries studied. To counter these impacts, adaptation would be expected (see Section 9.6). Table 9-3 stresses the cost of total protection rather than other possible adaptation options, which may have lower costs. Assuming that costs will accrue uniformly over 100 years, the annual protection costs—as a percentage of present GNP—are highest for the Marshall Islands at 7% (Holthus *et al.*, 1992) and St. Kitts-Nevis at 2.7% (Cambers, 1994). This supports the conclusion that some small islands have a high vulnerability to sea-level rise. However, Kiribati has a similar setting to the Marshall Islands, yet the estimates of protection costs are much smaller, at 0.1% of present GNP (Woodroffe and McLean, 1992). This reflects important differences in assumptions about the meaning of total protection. In Kiribati, local engineers have selected existing low-technology, low-cost gabions to protect the atoll, whereas in the Marshall Islands large and expensive sea walls have been utilized to determine the costs. This comparison shows one of the weaknesses of the Common Methodology and the need to assess a wider range of response options in future vulnerability assessment studies.

In many locations, beaches are likely to require nourishment to protect tourist infrastructure because existing urban and tourist infrastructure could be damaged and destroyed. The amount of sand required to maintain a beach in the face of long-term sea-level rise is uncertain (Stive *et al.*, 1991); in some case studies, the costs of beach nourishment could dominate basic response costs if countries invest in such an adaptation option (Dennis *et al.*, 1995b; Nicholls and Leatherman, 1995a; Volonté and Nicholls, 1995). There is also the question of the availability of sufficient sand resources. The usual source is suitable-grade nearshore deposits, if available. However, the implication of the removal of such deposits must be carefully considered in terms of its effect on the coastal sediment budget and the nearshore wave climate.

In many industrialized countries, the main potential loss from sea-level rise seems to be coastal wetlands, as well as sandy beaches in some countries (e.g., Mimura *et al.*, 1994).

Box 9-3. The Vulnerable Situation of Small Islands

Many small island countries could lose a significant part of their land area with a sea-level rise of 50 cm to 1 m. The Maldives, for example, have average elevations of 1 to 1.5 m above existing sea level (Pernetta, 1992). Although bio-geophysical processes may counter land losses (see Section 9.4), the threat of submergence and erosion remains; this could convert many small islands to sandbars and significantly reduce the usable dry land on the larger, more populated islands. Saltwater intrusion and loss of the freshwater lens may be an equally binding constraint on human habitation in some islands, particularly smaller atolls (Leatherman, 1994).

The available case studies have shown that small islands—most particularly, coral atolls such as the Marshall Islands (Holthus *et al.*, 1992)—are heavily oriented toward coastal activities and hence are vulnerable to sea-level rise (e.g., Cambers, 1994; Fifita *et al.*, 1994). At the same time, their relatively small economies may make the costs of adaptation prohibitive. In global terms, the population of small islands is relatively small, but a number of distinct societies and cultures are threatened with drastic changes in lifestyle and possibly forced abandonment from ancestral homelands if sea level rises significantly (Roy and Connell, 1991).

Even the less-vulnerable small islands would suffer significant economic effects from the loss of beach tourism and recreation areas because of sea-level rise and, possibly, more storms leading to increased beach and reef erosion. In 1988, among the Caribbean islands, income from tourism as a percentage of GNP was 69% for Antigua and Barbuda and 53% for the Bahamas; for a dozen other Caribbean islands, tourism revenues make up more than 10% of the GNP (Hameed, 1993). The Indian Ocean islands of the Seychelles and the Maldives also have seen a steady growth in tourism. In 1991, total receipts from tourism generated foreign exchange earnings of $94 million in the Maldives. This represented some 74% of the country's total foreign exchange earnings. Since 1985, tourism has been the single biggest contributor to the GNP of the Maldives. Tourism to developing countries has increased significantly in recent years, and small island developing states have experienced a particularly rapid increase. Tourist numbers to Mauritius, for example, have increased from 1,800 visitors in 1968 to 180,000 in 1988 (UNEP, 1991).

Given accelerated sea-level rise, first-order estimates suggest that substantial investment would be required in some developing countries in order to protect urban areas and maintain related activities such as beach tourism. Nine small island states appear in the list of countries facing the highest coastal protection costs as a percentage of their GNP. The global average percentage required annually for coastal protection is 0.037%; however, for many small islands it is significantly higher—up to 34% for the Maldives (OECD, 1991). To explore the full range of potential responses, more comprehensive assessment of the available adaptation options in these vulnerable settings is urgently required.

However, a change in the frequency, intensity, or distribution of extreme weather events could have implications for urban areas and related capital assets in countries such as Japan, Australia, the United States, and some countries bordering the North Sea.

From the above it is clear that all coastal zones of the world are vulnerable to the range of possible impacts from sea-level rise and other climate-induced impacts, although to different degrees. Studies using other approaches than the Common Methodology support this conclusion. Small island developing states are often judged to be among the most vulnerable countries. In Box 9-3, case material is presented for small islands, centering chiefly on threats to small economies dominated by tourism.

9.5.2.3. *Global Vulnerability Assessment*

In addition to local and country vulnerability assessments, a Global Vulnerability Assessment (GVA), which provides a worldwide estimate of the socioeconomic and ecological implications of accelerated sea-level rise (Hoozemans *et al.*, 1993) has been conducted, using the same scenarios as the Common Methodology. The GVA has provided estimates of the following impacts: *population at risk*, the average number of people per year subject to flooding by storm surge on a global scale; *wetlands at loss*, the ecologically valuable coastal wetland area under serious threat of loss on a global scale; and *rice production at change*, the changes in coastal rice yields as a result of less-favorable conditions due to sea-level rise in South, Southeast, and East Asia.

Recently, an extension of the GVA has been prepared using a more refined approach to estimate flooding probabilities (Baarse, 1995). Sea-level rise scenarios of both 50 cm and 1 m have been considered. The data sets available for global-scale analysis are limited, and important assumptions are necessary with regard to storm-surge probability and population distribution. Also, increases in wave height and wave run-up have not been taken into account in these analyses, and neither have socioeconomic changes such as population growth. Therefore, the results of both studies must be considered as first-order estimates.

Some conclusions drawn from Hoozemans *et al.* (1993) and Baarse (1995) include:

- Presently, some 200 million people are estimated to live below the "maximum" storm-surge level (the once-per-1000-years storm-surge level). Based on this population estimate, as well as on first-order estimates of storm-surge probabilities and existing levels of protection, 46 million people are estimated to experience flooding due to storm surge in an average year under present conditions. Most of these people live in the developing world.
- The present number of people at risk will double if sea level rises 50 cm (92 million people/yr) and almost triple if it rises 1 m (118 million people/yr).
- The average number of people who will experience coastal flooding more than once per year will increase considerably under both scenarios (80–90% of the respective populations at risk). This estimate underlines that many people will have to adapt to sea-level rise by moving to higher ground, increasing protection efforts or other adaptation options (see Section 9.6).
- Because of regional differences in storm-surge regimes, the increase of flood risk due to sea-level rise is greater than average for the Asian region (especially the Indian Ocean coast), the south Mediterranean coast, the African Atlantic and Indian Ocean coasts, Caribbean coasts, and many of the small islands.
- All over the world, coastal wetlands are presently being lost at an increasingly rapid rate, averaging 0.5–1.5% per year. These losses are closely connected with human activities such as shoreline protection, blocking of sediment sources, and development activities such as land reclamation, aquaculture development, and oil, gas, and water extraction.
- Sea-level rise would increase the rate of net coastal wetland loss. Losses of coastal wetlands of international importance are expected to be greater than average for the coasts of the United States, the Mediterranean Sea, the African Atlantic coast, the coast of East Asia, and the Australian and Papua New Guinean coast.
- Approximately 85% of the world's rice production takes place in South, Southeast, and East Asia. About 10% of this production is located in areas that are considered to be vulnerable to sea-level rise, thereby endangering the food supply of more than 200 million people.
- Less-favorable hydraulic conditions may cause lower rice production yields if no adaptive measures are taken, especially in the large deltas of Vietnam, Bangladesh, and Myanmar.

In summary, the GVA confirms that sea-level rise will have global impacts and reinforces the need for more refined vulnerability assessments at regional and local scales.

9.5.2.4. *Overview of Impact Assessment*

Vulnerability assessment has demonstrated that certain settings are more vulnerable to sea-level rise, including small islands (particularly coral atolls), nations with large deltaic areas, coastal wetlands, and developed sandy shores. However, vulnerability assessment has been less successful in assessing the range of response options to deal with the problems of climate change. Therefore, vulnerability analysis has further utility for countries and areas where none has yet been carried out or where only preliminary studies are available. Even in many areas with a completed vulnerability assessment, an assessment of additional sea-level rise scenarios, scenarios of other impacts of climate change, and a wider range of response options remains necessary. This entails a greater emphasis on local conditions and careful evaluation of progressive adaptation options.

Problems and deficiencies with the Common Methodology have been indicated in several papers in O'Callahan (1994) and McLean and Mimura (1993) [e.g., Kay and Waterman (1993)], and recommendations have been made for integrating vulnerability assessments into the process of coastal zone management (WCC'93, 1994). In order to continue vulnerability assessment studies in a more complete form, approaches should be developed that more readily meet biogeophysical, socioeconomic, and cultural conditions, as well as governmental and jurisdictional arrangements (e.g., Yamada *et al.*, 1995). Common approaches or frameworks that are tailored to the geographic circumstances and needs of each nation should be consistent with the IPCC Technical Guidelines for Assessing Climate Change Impacts and Adaptation (Carter *et al.*, 1994) and need to take into account and correct the weaknesses found with the Common Methodology (McLean and Mimura, 1993; WCC'93, 1994).

9.6. Response Strategies

There is no doubt that the threat of climate change and sea-level rise has focused attention on coastal zones and small islands and awakened awareness of the vulnerability of the world's coastal regions in general—and to low-lying coasts, tidal deltas, and small islands in particular. IPCC CZMS (1990, 1992) have distinguished three groups of response strategies: (planned) retreat, accommodate, and protect. The first involves strategic retreat from or the prevention of future major developments in coastal areas that may be impacted. The second includes adaptive responses such as elevation of buildings, modification of drainage systems, and land-use changes. Both strategies are based on the premise that increases in land loss and coastal flooding will be allowed to occur and that some coastal functions and values will change or be lost. On the other hand, these strategies help to maintain the dynamic nature of coastal ecosystems and thus allow them to adapt naturally. The third strategy involves defensive measures and seeks to maintain shorelines at their present position by either building or strengthening protective structures or by artificially nourishing or maintaining beaches and dunes. This strategy could involve the loss of natural functions and values.

As discussed in Section 9.5, vulnerability assessment of various forms provides a range of procedures for a first overview of the consequences of climate change to coastal nations. These procedures also include guidance to a survey of response strategies and a country's capacity to implement those strategies in the context of management and planning of coastal areas. For the majority of coastal nations surveyed, the typical problems posed by sea-level rise (i.e., increased coastal erosion, inundation, flooding, saltwater intrusion) are not uniformly threatening. This does not imply that serious problems will not arise—only that there may be feasible, cost-effective adaptation options.

From Section 9.5, four major areas of concern regarding sea-level rise have emerged: inundation and increased flooding of low-lying islands, inundation and increased flooding of large parts of densely populated deltaic areas, loss of coastal wetlands, and erosion of developed sandy coasts. Each of these areas may require different options to reduce or prevent the prospective adverse impacts associated with biogeophysical changes caused by climate change and sea-level rise. In addition, strategies to reduce the vulnerability of coastal zones and small islands to climate change and sea-level rise should not be seen independently of the resolution of short-term problems arising primarily from human activities. Effective adaptation to climate change and sea-level rise therefore requires a flexible coastal management strategy at all timescales, that incorporates and integrates both short-term and long-term goals.

Although one may argue that there is still a considerable amount of time to implement a response strategy, present-day coastal development often adversely influences the effectiveness of long-term adaptation options (WCC'93, 1994). Moreover, considerable time lags are often involved between the planning and implementation of adaptation options (Vellinga and Leatherman, 1989). The World Coast Conference therefore has concluded that strengthening planning and management capabilities for coastal areas should be delayed no further (WCC'93, 1993, 1994).

Assessing the full social costs of adaptation to climate change is a complicated, often controversial, issue, for which a range of techniques will be required. Apart from estimates of protection costs for a number of countries (see also Table 9-3), this chapter does not offer a comprehensive assessment of these full social costs. This has been done in Chapter 6, *The Social Costs of Climate Change: Greenhouse Damage and the Benefits of Control*, and Chapter 7, *A Generic Assessment of Response Options*, of the IPCC Working Group III volume, which also discuss the techniques available for assessing adaptation costs. A number of cost–benefit studies have been undertaken that attempt to determine optimal response strategies in the face of sea-level rise. Studies include Titus (1991), Nijkamp (1991), Fankhauser (1995), and Turner *et al.* (1995a).

9.6.1. Adaptation Options

There is a wide array of adaptation options that can be employed to retreat, accommodate, and protect. Table 9-4 outlines the options within these three strategies, as listed in the IPCC First Assessment Report (IPCC, 1990).

Box 9-4. Approaches to Coastal Adaptation to Climate Change: Two Examples

West and Central Africa: The coastal nations of West and Central Africa (e.g., Senegal, Gambia, Sierra Leone, Nigeria, Cameroon, Gabon, Angola) have mostly low-lying lagoonal, erosive coasts—and hence are likely to be threatened by sea-level rise, particularly since most of the countries in this area have major, rapidly expanding cities on the coast (Tobor and Ibe, 1990; Adam, 1995; Dennis *et al.*, 1995b; G.T. French *et al.*, 1995). Ibe (1990) has found that large-scale protective engineering measures are impractical in the region because of the high costs to those countries. Instead, low-cost, low-technology, but effective measures—such as permeable nonconcrete floating breakwaters; artificial raising of beach elevations; installation of riprap; timber groins; and so forth—are considered to be more sensible. Ibe (1990) has noted that "fortunately, outside the urbanized centers, the coasts are almost in pristine condition and largely uninhabited. Where coasts are deemed highly vulnerable, total ban of new development is absolutely necessary."

The Netherlands: The Dutch Impacts of Sea-Level Rise on Society (ISOS) study has assessed consequences and the possible responses for water management and flood protection in the Netherlands (Peerbolte *et al.*, 1991). Various scenarios of climate change have been considered, including sea-level rise, changes in river discharges, and changes in storm patterns (i.e., wind direction, storm frequency and intensity). Possible adaptation options, including investments in infrastructure and soft measures such as beach and dune nourishment, have been evaluated and optimized in time for the different sets of scenarios. If sea level were to rise by 60 cm over the next century, $3.5 billion would have to be spent on raising dikes and other safety infrastructure, $500 million on preserving the dune areas, $900 million on adapting flood-prone residential and industrial areas and harbors, and $800 million on adapting water-management facilities. An unfavorable change in storm pattern alone would have the same magnitude of impacts. The occurrence of sea-level rise in combination with the implementation of protective measures will further lead to losses of wetland and intertidal area. These losses cannot be prevented by any realistic additional measures.

Table 9-4: Response strategies to sea-level rise (IPCC, 1990).

Present Situation

(Planned) Retreat

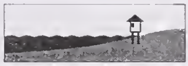
Emphasis on abandonment of land and structures in highly vulnerable areas and resettlement of inhabitants

- Preventing development in areas near the coast
- Conditional phased-out development
- Withdrawal of government subsidies

Accommodate

Emphasis on conservation of ecosystems harmonized with the continued occupancy and use of vulnerable areas and adaptive management responses

- Advanced planning to avoid worst impacts
- Modification of land use, building codes
- Protection of threatened ecosystems
- Strict regulation of hazard zones
- Hazard insurance



Protect

Emphasis on defense of vulnerable areas, population centers, economic activities, and natural resources

- Hard structural options
  - Dikes, levees, and floodwalls
  - Sea walls, revetments, and bulkheads
  - Groins
  - Detached breakwaters
  - Floodgates and tidal barriers
  - Saltwater intrusion barriers
- Soft structural options
  - Periodic beach nourishment (beach fill)
  - Dune restoration
  - Wetland creation
  - Littoral drift replenishment
  - Afforestation

Traditionally, the emphasis has been on engineering responses to coastal erosion and protection against flooding, with action often being triggered in response to an extreme event. Now the range of options has expanded to include nonstructural adaptation consisting primarily of zoning, building codes, land-use regulation, and flood-damage insurance, with more emphasis on a precautionary approach. Two different approaches to adaptation to anticipated climate change are discussed in Box 9-4.

IPCC CZMS (1990) has identified the environmental, economic, cultural, legal, and institutional implications of the three response strategies. Vulnerability assessments have since made clear that the extreme options of retreat and full protection highlight the negative effects and overestimate the potential costs and losses from climate change and sea-level rise. Yet adaptation options in low-lying island states (e.g., the Marshall Islands, the Maldives) and for nations with large deltaic areas (e.g., Bangladesh, Nigeria, Egypt, China), which have been identified as especially vulnerable, are problematic because the options have not been fully evaluated but appear limited and potentially very costly. Even without climate change and associated sea-level rise, these nations will continue to experience rapidly increasing vulnerability to natural coastal hazards due to high rates of population growth, increased demands, continued unsustainable exploitation of resources in the coastal zone, and development in upstream catchment areas. Continued natural and possible anthropogenic subsidence (relative sea-level rise) of large river deltas will increase the risk from storm surges. Strategies must be devised to reduce the economic damages and social hazards well before climate change and associated sea-level rise become a significant factor (Han *et al.*, 1995b; Boesch *et al.*, 1994). For these situations, conventional adaptation options will have to be enacted as a first step, while innovative or radical solutions—for example, controlled flooding and sedimentation to harness the natural capability of a delta to respond to sea-level rise—are examined for their effectiveness, environmental impact, social acceptability, and economic efficiency.

Heavily populated areas are primary candidates for structural protection measures such as dikes, sea walls, breakwaters, and beach groins. Because these are expensive options, the use of economic evaluation principles—especially risk assessment and benefit-cost analysis—can provide useful tools in deciding whether to protect or retreat, as well as where such infrastructure investments ought to be placed in order to maximize national or regional social and economic welfare (Carter *et al.*, 1994).

Some of the more detailed recent studies of response strategies to sea-level rise have been accomplished for coastal urban areas. In all instances, the problems of sea-level rise are considered to be serious. Many examples can be found in Frassetto (1991) and Nicholls and Leatherman (1995a), including Venice, Hamburg, London, Osaka, St. Petersburg, Shanghai, Hong Kong, Lagos, Alexandria, Recife, and Tianjin. However, Devine (1992) has argued that the shantytown areas found in many coastal cities may be particularly vulnerable to climate change, and adaptation options are uncertain. Chapter 12 further discusses impacts of and adaptation options to climate change in human settlements, including coastal cities.

Kitajima *et al.* (1993) have undertaken a comprehensive analysis of the range of likely structural measures that would be required to respond to a 1-m sea-level rise at 1,100 Japanese ports, harbors, and neighboring areas, as well as their estimated costs. The cumulative undiscounted costs have been estimated at $92 billion. Of that sum, about $63 billion is for raising port facilities and $29 billion is for adjoining shore protection structures (e.g., breakwaters, jetties, embankments). This cost estimate covers about 25% of Japan's coastline; other residential areas would also have to be protected, if that were the most cost-effective option. Further costs would be incurred to maintain existing standards of protection for populated areas as sea level rises (Mimura *et al.*, 1994). For a rise of 1 m, total costs would exceed $150 million. Further, natural shores could be largely lost from Japan's coast. It should be noted that, on an average annual basis, the costs constitute a small fraction of the GNP.

Adaptation can exploit the fact that coastal infrastructure is not static. There is a turnover of many coastal facilities through major rehabilitation, construction, and technological changes in ports, harbors, and urbanized areas, averaging roughly 25–30 years. Therefore, there will be recurring opportunities to adapt to sea-level rise, especially if the rate is relatively slow and construction and maintenance plans can be taken into account in land-use planning, management, and engineering design criteria (Stakhiv *et al.*, 1991; Yim, 1995). Moreover, experience with allowances for accelerated sea-level rise is limited but growing (e.g., Nicholls and Leatherman, 1995b). The interaction of different aspects of climate change should be considered. For instance, given the likelihood of both sea-level rise and a decrease in the return period of intense rainfall events (see Section 9.3), more consideration of future drainage capacity requirements in low-lying coastal areas may be prudent (Titus *et al.*, 1987; Nicholls *et al.*, 1995).

Some structural examples of proactive adaptation include:

- In the early 1990s, design standards for new seawalls in The Netherlands and eastern England were raised 66 cm and 25 cm, respectively, to allow for accelerated sea-level rise. This has been in response to the IPCC90 best estimate for future sea-level rise; the different magnitudes reflect a 100-year and 50-year planning horizon, respectively.
- The Massachusetts Water Resources Authority has included an additional 46 cm of height in the Deer Island sewage treatment plant. This is a safety factor to maintain gravity-based flows under higher sea levels without the additional costs of pumping.
- In Hong Kong, the West Kowloon reclamation is being built 80 cm above earlier design levels to allow for sea-level rise and/or unanticipated subsidence (Yim, 1995). In this case, costs have increased by less than 1%; future reclamations are expected to be similarly raised, and existing reclamations may be raised as part of the redevelopment cycle.

Enlarged setbacks to allow for expected shoreline recession, most notably in some states in Australia (Caton and Eliot, 1993), would enable planned retreat to accommodate climate change impacts. A variant on fixed setbacks is presumed mobility—whereby coastal residents are allowed to live at the shore but give up their right to protect the shore if it retreats in response to climate change or other causes (Titus, 1991). To counter the coastal squeeze of wetlands and maintain their habitat and flood-buffering functions, managed retreat on estuarine shorelines is increasingly favored in the United Kingdom (Burd, 1995). This involves setting back the line of actively maintained defense to a new line inland of the original and promoting the creation of intertidal habitat on the land between the old and new defenses.

9.6.2. *Implementation Considerations*

To date, the assessment of possible response strategies has focused mainly on protection. There is a need to better identify the full range of options within the adaptive response strategies: protect, accommodate, and retreat. Identifying the most appropriate options and their relative costs and implementing these options while taking into account contemporary conditions as well as future problems such as climate change and sea-level rise will be a great challenge in both developing and industrialized countries. The range of options will vary among and within countries, and different socioeconomic sectors may prefer competing adaptation options for the same areas. Experience shows that intersectoral conflicts are a major barrier to improved coastal management (WCC'93, 1994). In the present context, they could also be a major barrier to adaptation to climate change. An appropriate mechanism for coastal

Box 9-5. Integrated Coastal Zone Management

ICZM involves comprehensive assessment, setting of objectives, planning, and management of coastal systems and resources, while taking into account traditional, cultural, and historical perspectives and conflicting interests and uses. It is an iterative and evolutionary process for achieving sustainable development by developing and implementing a continuous management capability that can respond to changing conditions, including the effects of climate change. ICZM includes the following:

- Integration of programs and plans for economic development, environmental quality management, and land use
- Integration of programs for sectors such as food production (including agriculture and fishing), energy, transportation, water resources, waste disposal, and tourism
- Integration of all the tasks of coastal management—from planning and analysis through implementation, operation and maintenance, monitoring, and evaluation—performed continuously over time
- Integration of responsibilities for various tasks of management among levels of government—local, state/provincial, regional, national, international—and between the public and private sectors
- Integration of available resources for management (i.e., personnel, funds, materials, equipment)
- Integration among disciplines [e.g., sciences such as ecology, geomorphology, marine biology; economics; engineering (technology); political science (institutions); and law].

planning under these varying conditions is integrated coastal zone management (ICZM) (see Box 9-5).

There is no single recipe for ICZM; rather it constitutes a portfolio of sociocultural dimensions and structural, legal, financial, economic, and institutional measures. There are many approaches as well as diverse institutional arrangements that can be tailored to the particular culture and style of governance. Yet a number of essential prerequisites can be identified (WCC'93, 1994). The first of these is the need for *initial leadership* for the planning process The initiative may consist of a centrally led "top-down" approach, a community-based "bottom-up" approach, or something in between. The second necessary element of ICZM is the provision of *institutional arrangements*. This may involve creating new institutions but more commonly will involve improving horizontal and vertical linkages between existing ones. Third, *technical capacity* (both technological and human capacities) is necessary for compiling inventories in the planning phase and during the implementation of the program, and for monitoring the changes. The final necessary element of ICZM is *management instruments*. These include tools ranging from directive to incentive-based, all with the aim of encouraging stakeholders to comply with the goals and objectives of the given ICZM program.

At both UNCED and at the World Coast Conference, ICZM has been recognized as the most appropriate process to deal with current and long-term coastal problems, including degradation of coastal water quality, habitat loss, depletion of coastal resources, changes in hydrological cycles, and, in the longer run, adaptation to sea-level rise and other effects of climate change.

The goal of ICZM is not only to address current and future coastal problems but also to enable coastal societies to benefit from a more efficient and effective way of handling coastal development. Most coastal areas are called on to provide multiple products and services. As demands on coastal resources continue to grow with increasing population and economic development, conflicts could become more common and apparent. ICZM should resolve these conflicts and implement decisions on the mix of uses that best serve the needs of society now and in the future. Also, ICZM is important in the context of the increasingly expressed concern for sustainable development. Sustainable use of any natural resource can be achieved only by having in place a set of integrated management tasks that are financed and carried out continuously (WCC'93, 1994).

There is a persuasive case for taking action about climate change now—to institute or expand ICZM and thus comply with the precautionary approach. Although the time lag between planning and investment in integrated (cross-sectoral) management is longer than that for single-sector management, the returns are significantly greater. A proactive approach to ICZM, in order to enhance the resilience of natural coastal systems and reduce vulnerability, would be beneficial from both an environmental and an economic perspective (Jansen *et al.*, 1995). In addition to reducing vulnerability and enhancing the resilience of developed coastal regions, such initiatives also can encompass the large lengths of shorelines that are presently undeveloped but may be subject to significant pressures in the coming decades. By acting now, future development may be designed to be sustainable and to accommodate the potential impacts of climate change and sea-level rise.

9.6.3. Constraints to Implementation

It is important for governments and policymakers to recognize that although a particular response strategy may appear initially to be appropriate, there are constraining factors that can determine how successfully that option can be implemented (SDSIDS, 1994).

The applicability of any option must be evaluated against (among other things) a background of a country's technology and human resources capability, financial resources, cultural and social acceptability, and the political and legal framework. This is not to suggest that these constraints are insurmountable but that decisionmakers must be realistic when considering the range of options available to them.

9.6.3.1. *Technology and Human Resources Capability*

For many countries, scarcity of (or lack of access to) appropriate technology and trained personnel will impose limits on the adaptation options realistically available. For example, the design, implementation, and maintenance of "state-of-the-art" civil works may be beyond the immediate reach of many developing nations unless there is technical assistance to provide the required technology and human skills. This is highlighted in vulnerability assessments for a number of countries, such as Tonga (Fifita *et al.*, 1994), Bangladesh (Khan *et al.*, 1994), and Belize (Pernetta and Elder, 1993).

Specifically in the case of protection and accommodation, there will be a need for ongoing maintenance and periodic replacement and upgrade. These activities will also require access to the relevant technology and skills to remain effective.

9.6.3.2. *Financial Limitations*

The implementation of any adaptation option—whether retreat, accommodate, or protect—will necessitate certain financial commitments from governments, although the level of required funding may vary widely from one option to another. In the case of planned retreat, substantial infrastructure would have to be rebuilt and settlements relocated to less-vulnerable areas, at high reinvestment costs. Adjustment strategies might entail acceptance of less-than-ideal circumstances, while simultaneously increasing the costs of reducing flood risks. Protection strategies almost always involve "hard" engineering structures, which are costly both to construct and to maintain. In the Maldives, for example, the present costs of shoreline protection are close to $13,000 per m; in Senegal, Benin, Antigua, Egypt, Guyana, the Marshall Islands, St. Kitts-Nevis, and Uruguay, maintenance of the existing shoreline against a 1-m rise in sea level could require substantial funding compared with the nation's GNP (Nicholls, 1995). However, it should be noted that national responses to climate change will more likely comprise a variable combination of planned retreat, accommodation, and protection; hence, lower-cost responses probably are available in some areas (e.g., Turner *et al.*, 1995a; Volonté and Nicholls, 1995).

Clearly, any combination of response strategies will be largely influenced by monetary considerations, necessitating both short-term investment and a commitment to longer-term maintenance and replacement costs. Many developing countries will find it especially difficult to meet such costs and will increasingly have to turn to donor countries and international agencies for assistance. In Kiribati, for instance, it has been demonstrated that implementation of protection measures especially will almost certainly require external assistance (Abete, 1993). Lack of adequate financial resources will also circumscribe a country's capacity to "purchase" appropriate technology and human skills required for the implementation of various options. Countries should therefore consider designing efficient, least-cost response plans, based on some realistic assessment of what their economies will be able to sustain (WCC'93, 1994).

9.6.3.3. *Cultural and Social Acceptability*

Although certain options may be technically and financially possible in a given set of circumstances, they may, at the same time, be culturally and socially disruptive. In some societies, resettlement, for example, would lead to dislocation of social and cultural groups and might even involve the loss of cultural norms and values and the assimilation of new ones. Additionally, an option involving planned retreat could mean the loss of access to communally owned resources and land entitlements, which might undermine the entire economic, social, and cultural base of some communities. Other adaptive measures, such as the construction of "hard" engineering structures, could cause the partial or total elimination of access to traditional fishing, hunting, and culturally important sites.

9.6.3.4. *Political and Legal Framework*

The extent to which a given response strategy can be successfully employed may well be influenced by political and legal considerations (Freestone and Pethick, 1990). Retreat options, for example, might prove infeasible given the policy and legal structures of the "receiving" area. Where international resettlement is indicated, these issues can become even more complex—as demonstrated by the plight of refugees worldwide. Further, some options will be incompatible with existing systems of land tenure and ownership and in some societies would necessitate a fundamental change in arrangements prior to implementation to avoid violating certain rights. Failing this, governments could be called upon to provide substantial compensation to communities for loss of property and resource-use rights.

Strategies that lead to coastal land loss might also have an undesirable impact on a country's Exclusive Economic Zone (e.g., Aparicio-Castro *et al.*, 1990). This could lead to international legal disputes concerning ownership and use of resources. In those circumstances, such options might not only be considered legally unacceptable but politically infeasible as well.

9.6.4. *Overcoming the Constraints*

As a step toward overcoming these constraints, the World Coast Conference was organized with the objective of bringing together coastal experts and policymakers to identify actions that can be taken to strengthen capabilities for progressive sustainable development and integrated coastal zone management. The conference participants acknowledged that there is an urgent need for coastal states to strengthen their capabilities, in particular with regard to the exchange of information, education and training; the development of concepts and tools; research, monitoring, and evaluation; and funding (WCC'93, 1993). The following are examples of measures that could improve capabilities for developing, implementing, and strengthening national programs for ICZM (WCC'93, 1993):

- Multidisciplinary studies and assessments to determine the potential importance of the coastal zone and its vulnerabilities, particularly those that limit its ability to achieve sustainable development
- An institutional body or mechanism to investigate the need and potential benefits and costs of developing an ICZM program
- A long-term and effective body or mechanism to prepare, recommend, and coordinate the implementation of a permanent ICZM program
- A continuing monitoring and assessment program to collect data, assess results, and identify the need for change or improvement
- An ongoing research program, including an investigation of the potential effects of global climate change, to improve the analytical foundation for the decisionmaking process
- A policy to increase the availability and accessibility of information to all interested parties
- Active support for local initiatives, exchange of practical and indigenous experiences, and enhancement of public participation
- Education, training, and public-awareness efforts to increase the constituency for ICZM
- Coordination of financial support for relevant activities and investigation of innovative sources for additional support.

Effective ICZM can be achieved by coordination among national, regional, and international organizations and institutions. This will help to avoid unnecessary duplication and develop the concepts, tools, and networks needed to facilitate the development and implementation of national programs, which is a complex process that can be accelerated and enhanced through international cooperation. Regional approaches can complement and strengthen activities at the national and international levels.

Various international initiatives have been undertaken to encourage and facilitate coordination and cooperation in both policy and research. Several United Nations organizations and other international governmental and nongovernmental organizations have developed programs aimed at strengthening ICZM capabilities at different levels. An overview of these activities is presented in WCC'93 (1994). In 1993, the IGBP launched its core project LOICZ, which aims to stimulate interdisciplinary scientific coastal research in the context of global change (Pernetta and Milliman, 1995).

Clearly, the wide range of uncertainty in human and natural variables that will affect ICZM emphasizes the need for continued research and monitoring. The results of scientific research and information from monitoring activities need to be integrated into policy development, planning, and decisionmaking throughout the ICZM process.

9.7. Research and Monitoring Needs

Although much has been achieved since the IPCC First Assessment in 1990, this chapter shows that the understanding of the likely consequences of climate change and sea-level rise is still imperfect. This situation can be improved only through a sustained research and monitoring effort, requiring a major commitment of resources at the national, regional, and global levels. The potential problems of small islands, deltas, coastal wetlands, and developed sandy coasts deserve particular attention as part of these efforts. Coastal zones and small islands illustrate the fundamental need for better coupling of research and models from the natural sciences and the social sciences to provide improved analytical capability and information to decisionmakers. An emphasis on understanding the impacts of climate change at the local and regional scales is essential.

There are a number of critical issues and priorities in ongoing research and monitoring, as initiated by IPCC CZMS (1990, 1992), that should be continued over the next few years to enable better decisionmaking concerning the possible impacts of climate change in coastal zones and small islands:

- Development of improved biogeophysical classifications and frameworks of coastal types for climate-change analysis, including the influence of human activities (IGBP-LOICZ has taken an important step in this direction)
- Investigations of geomorphological and biological responses of coastal types and critical ecosystems to climate change and sea-level rise, with specific attention to the response of seagrass to climate change as well as potential changes in sediment budgets
- Improved methodologies for incorporating existing, high-quality historical and geological coastal-change data into response models for climate change
- Improved coastal-processes data (especially in developing countries), based on instrumentation (tide gauges, current meters, wave recorders, etc.), as well as improved capacity to interpret and analyze the data
- Improved databases for vulnerability assessment and adaptation planning on coastal socioeconomic trends, such as population changes and resource utilization and valuation, taking into consideration differences in sociocultural characteristics of countries and ethnic groups

- Extension of new and existing vulnerability assessment studies to include a range of local scenarios of sea-level rise (rather than a single scenario), other possible impacts of climate change such as changing storminess or precipitation, and an assessment of the range of possible adaptation strategies
- Continued education and training relevant to vulnerability assessment and integrated coastal zone management, employing, as far as practicable, standardized methodologies and frameworks.

Some ongoing initiatives have already been undertaken to address these priorities. For example, the Intergovernmental Oceanographic Commission (IOC) coordinates a Global Sea Level Observing System (GLOSS). However, there still are many gaps, and the system requires increased international support and coordination. IGBP-LOICZ aims to stimulate interdisciplinary scientific coastal research in the context of global change. Focus 2 of LOICZ aims to investigate coastal biogeomorphological interactions under different global-change scenarios. It focuses on the interaction between major ecosystem types with the sedimentary environment and aims to assess the implications of ecosystem perturbations on coastal stability with a rise in sea level. Focus 4 is especially relevant for integrated coastal zone management because it addresses the socioeconomic impacts of global change on coastal zones and aims to investigate how improved strategies for the management of coastal resources can be developed.

New initiatives also are required, as has been recognized by participants of the World Coast Conference (WCC'93, 1994). Increased efforts are needed mainly in the social sciences and adaptation to climate change, including the development of:

- Integrated coastal-response models, which seek to combine the interactions of biogeophysical, socioeconomic, and climate-change factors, incorporating the knowledge and technologies of traditional societies and local peoples
- Methods to quantify the benefits of integrated coastal zone management
- A broad framework for the analysis, planning, and management of coastal zones in the context of climate change, recognizing the co-evolution of natural and social systems.

Such a framework would encourage nations in the formulation and implementation of ICZM strategies and programs that are appropriate to climate change and fully take into account the existing environmental, social, cultural, political, governance, and economic contexts. This would help to fulfill the recommendations made by IPCC CZMS (1990).

To facilitate these goals, an international conference to share experience on coastal impacts and adaptation to climate change might be useful, building on the success of earlier meetings of the IPCC Coastal Zone Management Subgroup and the World Coast Conference. Particular targets for such a conference could include:

- An updated assessment of coastal vulnerability to climate change
- Examples of biogeophysical/socioeconomic integration in coastal research and coastal management
- Testing of the framework for ICZM via case studies in a range of countries or regions.

These activities could assist coastal nations in meeting their obligations under Agenda 21 of UNCED.

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This chapter is only one small step on the road to global sustainable coastal development and could not have been written if many earlier steps had not been taken. For many decades, scientists and policymakers from all over the world have devoted themselves to coastal research and management; the list of references below reflects only a minor part of their efforts. Hence, the authors would like to thank every person and institution who has contributed to the increased understanding of coastal systems and the growing awareness of the importance of their healthy functioning. Special thanks are due to the contributors and reviewers of this chapter and to Mark Naber and Willem Storm (National Institute for Coastal and Marine Management, The Netherlands), who prepared the figures.

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<u>Impacts on Coastal Areas</u>

Q28. On page 15 of your written testimony you also state the following:

"Coastal Areas: Even if concentrations of greenhouse gases are stabilized in the future, sea level would continue to rise long after, perhaps for several centuries, and reach levels much higher than projected for the next 100 years. For example, after an equivalent doubling of CO2, the IPCC expects sea level to rise by 6 - 38 inches over the next century, with a "best estimate" of 20 inches, but the equilibrium sea level rise several centuries in the future is estimated to be at least 6 feet. Rising sea level erodes beaches and coastal wetlands, causes the gradual inundation of low lying areas, leading to human habitat loss and increasing the vulnerability of coastal areas to flooding from storm surges and intense rainfall. The IPCC estimates that 20 inches of sea level rise would double the population at risk from storm surges, from roughly 45 million at present to over 90 million world-wide. A three-foot rise would triple the number of people exposed. Increases in coastal area populations are likely to further increase the number of people at risk.

- **Along U.S. coasts, a 20-inch rise could inundate more than 5000 square miles of dry land and an additional 4000 square miles of wetlands if not protective measures are taken. A three-foot rise would have greater impact, inundating much of the Southern tip of Florida among other areas.**

- **Internationally, low-lying areas, such as parts of the Maldives and Bangladesh, would be completely inundated by a three-foot sea level rise, creating large numbers of environmental refugees, which put stress on governments and social structures. 72 million people in China would be affected, assuming existing levels of coastal development."**

Please document these statements.

A28. The IPCC estimates of how much the sea will rise are found in the 1995 report, Climate Change 1995 - The Science of Climate Change (copy attached). All of the statements on the consequences of sea level rise are found in the 1998 report *Regional Impacts of Climate Change* except for the ones about the number of peoples at risk sue to flooding. The latter comer from Chapter 9 of the 1995 IPCC report *Climate Change 1995 - Impacts; Adaptations and Mitigation of Climate Change: Scientific-Technical Analysis.* This chapter was provided as an attachment for Q27 above. Also from this chapter are the estimates of the areas of various low lying nations that would be inundated by a rise in sea level.

The estimates of the amount of land flooded with a 20-inch global sea level rise (which would be 24 inches along the US coast) are found in Titus et al, 1991

(Coastal Management, Volume 19, pages 171-204. They are also posted on the internet at http://www.erols.com/jtitus/Holding/NRJ.html. For a map of the impact on South Florida, see http://www.erols.com/dickpark/SLAMM.htm, which was prepared using the model reported by Park, et al. in EPA's 1989 Report to Congress on the Potential Impacts of Global Climate Change on the United States.

Impacts on Agriculture and Food Supply

Q29. On pages 15 and 16 of your written testimony you also state the following:

"Agriculture and Food Supply: Agriculture is highly dependent on a number of variables that are likely to be affected by climate change, including weather patterns, longer term patterns of climate variability, and, most importantly, water availability. Climate change is likely to lead to increased crop yields in many areas, but decreased yields in others, even for the same crop. The magnitude of these changes can exceed +/- 30 or 40 percent for some crops and locations. Despite these potentially large changes in yields, average global food production is not expected to change substantially. This is because farming practices are considered to be highly adaptable to different climates, because production of important food crops can shift to new locations in response to changes in climate, and because CO2 has beneficial effects for plant photosynthesis and water use efficiency that can offset some deleterious effects of changes in climate. Impacts are likely to vary considerably across regions and some regions may suffer substantial reductions in agricultural production. In general, developing countries are more vulnerable to losses than are developed countries.

- **Large reductions in soil moisture could significantly reduce flexibility in crop distribution and increase demands on water resources infrastructure.**

- **Increases in the range of pest habitat could increase vulnerabilities to pests and demand for, and use of, pesticides.**

- **In the United States, large areas of the eastern and central regions of the country face moderate to severe drying. Drought could become more frequent, particularly in the Great Plains."**

Please document these statements.

A29. Chapter 13 of the document *Climate Change 1995 – Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses* summarizes the IPCC's most recent findings on impacts and adaptations of agriculture in a changing climate. A copy of this chapter of the document has already been attached for the answer to question 13.

Unresolved Scientific Issues Relating to the Modeling of the Impact of Future Potential Greenhouse Gas Emissions on Global Temperature

Q30. What are the greatest unresolved scientific issues relating to the modeling of the impact of future potential greenhouse gas emissions on global temperature in order of importance?

Q31. How, by whom and where are the issues identified in the response to question 29 addressed by the U.S. Global Change Research Program?

Unresolved Scientific Issues Involved in Projecting Future Temperature Increases and the Impacts Thereof

Q32. What are the greatest unresolved scientific issues involved in projecting future temperature increases and the impacts thereof?

Q33. How, by whom and where are the issues identified in the response to question 32 addressed by the U.S. Global Change Research Program?

Combined answers to Question 30-33: There is no prioritized listing of the most important unresolved questions relating to predicting the effect of future emissions on global climate. However, there is general agreement on the major issues, as reflected in part by the results of the World Climate Research Program conference last year, a meeting at which the US scientific community was well represented. In addition, based on a study sponsored by the USGCRP, a more directed breakdown of science questions and research priorities, titled Global Change: Pathways for the Next Decade, is to be released by the National Research Council later this spring. Issues relating to modeling of the climatic response to greenhouse gases are intimately tied to these process-related questions, as models can only be as good as our understanding of the processes they represent. Some of the major unresolved issues are as follows:

Role of Natural Fluctuations, such as El Niño, in Climate and Their Predictability: Any temperature signal resulting from forcing by greenhouse gases must manifest itself against the background of natural variability. For example, we know that the present El Niño event is part of a natural phenomenon that is a characteristic of the distribution of the Earth's oceans and land masses. However, the issue of whether the duration and frequency of El Niño events has been affected by greenhouse gases is an open question. Other natural climate patterns acting on longer periods than El Niño will also influence the planet's response to greenhouse gases. For example, the North Atlantic Oscillation, a decade-scale seesaw in atmospheric pressure between the North and South Atlantic, has a dramatic influence on the distribution and intensity of storms in the Atlantic.

Examining the issues of natural climate variability requires analysis of long-term data records and obtaining new data on a global basis. NASA is undertaking extensive reprocessing of existing satellite data to produce the most consistent global records possible as part of its Pathfinder program. Longer-term records are produced through analyses of existing surface records by NOAA and through support for paleoclimatic investigations through NSF and NOAA. This year also marks the beginning of a new era of satellite observations of the Earth with the launch of the EOS AM-1 platform, which will bring a comprehensive suite of sensors to studies of the ocean, land, atmosphere and cryosphere.

Programs examining the mechanisms and predictability of climate variations are ongoing, and their benefits are being realized in the predictions of the 1997-98 El Niño. Research into making even longer-range and more globally extended predictions of El Niño and other seasonal-to-interannual climate phenomena are central parts of the scientific programs of NOAA, NASA and NSF, done in coordination with the international Program on Climate Variability and Predictability (CLIVAR).

Models occupy a central role in both the analysis of natural and anthropogenic climate change. Research into advancing the capabilities of climate models is a prominent component of the science programs of DOE, NSF, NOAA and NASA.

Impact of Aerosols on the Climate System: Aerosols, defined as a suspension of liquids or solids in a gas, can have a marked influence on climate and represent a major uncertainty in our ability to predict climate. They include sulfates, soot, biomass smoke, nitrates, and mineral dust. They exert a direct effect on climate by reflecting, absorbing and emitting radiation, and an indirect effect by influencing the properties of clouds. Overall, they exert a cooling influence over large but localized regions of the globe. These regional changes to the energy balance influence the larger-scale effects by modifying the circulation of the atmosphere.

Several international projects have measured the impact of both natural and anthropogenic aerosols on the radiative balance of the Earth. Direct measurements of aerosol properties have enhanced confidence in estimates of their effects on the global radiative balance. Significant new measurements of aerosols are planned as part of USGCRP. EOS-AM observations will include measurements of aerosol and cloud properties, and the objective of the EOS CHEM mission scheduled for launch in 2002 is to provide comprehensive observations of the chemistry and dynamics of the Earth's atmosphere from the ground to the stratosphere.

Role of the Ocean in Climate Change: Because the upper three meters of the ocean have a heat capacity equal to that of the entire atmosphere, the ocean will exert a strong influence on the timing and extent of any climate change. As such, the role of the ocean in climate change, particularly on longer time scales, remains a major scientific issue. Analysis of the recently completed World Ocean

Circulation Experiment, which included the first global survey of the world's oceans, is ongoing. Results of WOCE, supported in the US by NSF, NOAA and NASA, will materially improve our understanding in this area. The ongoing TOPEX/Poseidon satellite altimetry mission of NASA is making major improvements in our observing capability of the dynamics of the ocean and its interaction with the atmosphere.

The Hydrological Cycle and Regional Water Conditions: Reducing uncertainties associated with the hydrological cycle and improving predictions of regional precipitation and runoff are major research issues for the USGCRP. Prediction of floods and droughts on watershed scales is an important practical payoff. A number of efforts are underway. The interactions between the atmosphere and the land surface over the Mississippi Basin are the subject of the Global Energy and Water Cycle Experiment's Continental-Scale International Project, which will employ the extensive array of ground-based weather observations in this area coupled with space-based remote-sensing. This project is supported by NOAA and NASA. The launch of EOS AM-1 will allow a new range of global measurements of the hydrological cycle: snow and ice distribution; global surface temperature (day and night); the distribution and structure of clouds; radiative energy fluxes; the distribution and properties of aerosols and water vapor.

Cloud Feedbacks: The role of clouds in the climate system is closely tied to both hydrological cycle questions and aerosols. It is a particularly critical issue, because models indicate that global climate is very sensitive to small changes in the amount and type of cloud distribution. A major effort in this area is DOE's Atmospheric Radiation Measurements program. In pursuit of its goal, the ARM Program establishes and operates field research sites in several climatically significant locales (e.g. the Great Plains, the western tropical Pacific and Alaska). Scientists collect and analyze data obtained over extended periods of time from large arrays of instruments to study the effects and interactions of sunlight, radiant energy, and clouds on temperatures, weather, and climate.

Regional Resolution of Potential Changes in Climate: Because the impacts of climate change need to be investigated at the regional scale of forests, grasslands, and communities, results from present simulations of global scale change do not directly provide the needed information for impact studies. A number of research activities are underway to improve regional detail in the forecasts of future climate change. DOE's CHAMMP program is assisting global modeling groups sponsored by NOAA, NSF, NASA, and DOE in using the most advanced numerical techniques and massively parallel computers in their calculations, working to represent Earth system processes in more detail. Efforts are also underway with funding from several USGCRP agencies to use results from the global models to drive fine scale regional models. In addition, a number of empirically based approaches are being used to estimate regionally detailed changes, analogous to techniques weather forecasters use to derive local forecasts from continental scale model simulations done for weather forecasting.

Responses of Environmental Systems: Estimating the types and nature of the impacts of changes in climate on the environment and society requires understanding how ecological, natural resource, and environmental systems function, and how their functioning will affect society and the economy. Many of the USGCRP agencies sponsor research focusing on how ecosystems will respond; one particular effort is the Program for Ecosystem Response which is a cooperative multi-agency effort to understand how forests and other systems will respond to both climate change and a rising CO2 concentration. Within the USGCRP, USDA focuses most attention on forests and food production; DOI most attention on public lands and water resources; EPA most interest on ecosystems and water and air quality; NSF on ecosystem function; and so forth. All of the USGCRP agencies are also cooperating in the just initiated national assessment of the consequences of climate change and variability for the United States, an effort that will summarize current understanding and identify uncertainties and issues requiring more intense attention.

Process of Preparing and Reviewing the U.S. Global Change Research Program Budgets and Projects

Q34. In the preparation of the FY 1999 U.S. Global Change Research Program budget, have independent experts been involved in recommending and reviewing budget priorities and projects?

Q35. If your answer to question 34 is yes, what was the process and which outside institutions/individuals were involved?

Q36. Was there any independent peer review or peer involvement to identify scientific uncertainties to be addressed by the FY 1999 U.S. Global Change Research Program?

Q37. If your answer to question 36 is yes:

Q37.1 What independent peer review or peer involvement took place and what were their suggestions/recommendations?

Q37.2 Were any suggestions/recommendations not addressed, and if so, why?

Q38. What are your current plans for involving the scientific community in identifying unresolved scientific questions and directing resources to address them?

Combined answers to Questions 34-38: The primary body on which we rely for scientific review of the USGCRP is the National Research Council's Committee on Global Change Research (CGCR). A listing of present membership of this committee is attached. In 1995, they completed a review of overall directions of the USGCRP, and the program has been responsive to these recommendations. The CGCR is currently completing a comprehensive report, Global Change: Pathways for the Next Decade, which will examine the major outstanding scientific questions for global change research and will make recommendations as to how they should be addressed over the next ten years. The report is presently in review at the NRC and is scheduled for release in April.

On the agency level, peer review is incorporated in the operations of the USGCRP agencies for programmatic and scientific planning. NASA, DOE and NOAA provide three examples. NASA's Earth System Science and Applications Advisory Committee provides advice in establishing broader program priorities in science and mission implementation. A similar function is provided for DOE's global change program by the Biological and Environmental Research Advisory Committee. Outside review of NOAA's global change activities is provided by the Climate and Global Change Review Panel. NSF and EPA also rely on the advice from panels of outside scientists for program planning purposes. Membership of these three committees is attached. Reports and minutes of the meetings of these panels are extensive, available and public. All agencies also use peer review in the selection and award of contracts and grants.

In responding to the upcoming recommendations from the Pathways report, a retreat of interagency program managers for USGCRP and key members of the CGCR is planned for May, after the release of the report. The objective is to produce a joint agenda for future directions for the USGCRP that will be reflected in future budgets. This joint agenda is to be described in a long-term strategic plan addressing these recommendations. The research agenda generated as part of the National Assessment will also be a major input to this strategic plan.

Composition of Outside Review Panels Described Above

NRC Committee on Global Change Research

Berrien Moore III, Chair	University of New Hampshire
James G. Anderson	Harvard University
Richard E. Balzhiser	Electric Power Research Institute
Eric J. Barron	Pennsylvania State University
Francis Bretherton	University of Wisconsin-Madison
Robert Costanza	University of Maryland
Gregory H. Canavan	Los Alamos National Laboratory
John A. Dutton	Pennsylvania State University

Edward A. Frieman	Scripps Institution of Oceanography
Robert A. Frosch	Harvard University
W. Lawrence Gates	Lawrence Livermore National Laboratory
Priscilla C. Grew	University of Nebraska - Lincoln
Margaret S. Leinen	University of Rhode Island
Diana Liverman	University of Arizona
Paul A. Mayewski	University of New Hampshire
James McCarthy	Harvard University
S. Ichtiaque Rasool	University of New Hampshire
Edward Sarachik	University of Washington
David Schimel	National Center for Atmospheric Research
William J. Shuttleworth	University of Arizona
Soroosh Sorooshian	University of Arizona
Karl K. Turekian	Yale University
Peter Vitousek	Stanford University

<u>NASA Earth System Science and Applications Advisory Committee</u>

Steve Wofsy, Chair	Harvard University
Eric J. Barron	Pennsylvania State University
Anthony Busalacchi	NASA Goddard Space Flight Center
Gregory H. Canavan	Los Alamos National Laboratory
Ralph Cicerone	University of California Irvine
John E. Estes	University of California
Paul Falkowski	Brookhaven National Laboratory
Murray Felsher	Associated Technical Consultants
Richard Goody	Harvard University (emeritus)
Dennis Hartmann	University of Washington
James Hansen	NASA Goddard Institute for Space Studies
Kathryn A. Kelly	University of Washington
George H. Leavesly	U.S. Geological Survey
Douglas Martinson	Lamont-Doherty Earth Observatory
Steve Pacala	Princeton University
Ignacio Rodriguez-Iturbe	Texas A&M University
John B. Rundle	University of Colorado
Denise Stephenson-Hawk	Clark Atlanta University
Louis Uccellini	NOAA/National Weather Service

<u>NOAA Climate and Global Change Review Panel</u>

Otis B. Brown, Chair	University of Miami
Ana Barros	Pennsylvania State University
Inez Fung	University of Victoria
Tom Ackerman	Pennsylvania State University
Francis Bretherton	University of Wisconsin-Madison

Chris Justice	University of Virginia
Diana Liverman	University of Arizona
Edward Sarachik	University of Washington
Richard C.J. Somerville	University of California, San Diego
Kevin Trenberth	NCAR, CGD
Ed Miles	University of Washington
Susan Solomon	NOAA Aeronomy Laboratory
Lonni Thompson	Ohio State University

DOE Biological and Environmental Research Advisory Committee

Keith O. Hodgson, Chair	Stanford University
Eugene W. Bierly	American Geophysical Union
Mina J. Bissell	University of California
E, Morton Bradbury	Los Alamos National Laboratory
Raymond F. Gesteland	University of Utah
Jonathan Greer	Abbott Laboratories
Richard E. Hallgren	American Meteorological Society
Willard W. Harrison	University of Florida
Dr. Franklin Harris	University of Tennessee
Leroy E. Hood	University of Washington
Fern Hunt	National Institute of Standards & Technology
David A.L. Jenkins	Sunbury on Thames
David T. Kingsbury	Chiron Corp.
Jill P. Mesirow	Center for Genome Research
James W. Mitchell	Bell Labs Innovations
Louis F. Petelka	University of Maryland Center for Environmental Science
Alan Rabson	National Cancer Institute
Melvin I. Simon	California Institute of Technology
Janet L. Smith	Purdue University
Henry N. Wagner, Jr.	John Hopkins Medical Institutions
Susan S. Wallace	University of Vermont
Warren M. Washington	National Center for Atmospheric
Robert M. White	National Academy of Engineering
James H. Wyche	Brown University

COMMITTEE ON SCIENCE
U.S. HOUSE OF REPRESENTATIVES

Hearing
on

The Road from Kyoto—Part 2:

Kyoto and the Administration's Fiscal Year 1999 Budget Request

Thursday, February 12, 1998

Post-Hearing Questions
Submitted to

The Honorable John H. Gibbons
Assistant to the President for Science and Technology
and
Director, Office of Science and Technology Policy

Post-Hearing Questions Submitted by the Honorable Mike Doyle (PA-18)

Carbon Sequestration

Q1. Please provide a list of all agencies that are pursuing carbon sequestration activities and indicate for each agency:

Q1.1. A brief description of the carbon sequestration activities being pursued.

Q1.2. The total budget — and the funding breakdown by project — for carbon sequestration activities in FY 1998 and proposed for FY 1999.

Q1.3. The projects that are new initiatives and those that are continuations of previous years' projects.

A1. Carbon sequestration is the process of capturing carbon dioxide and keeping it out of the atmosphere where it would trap heat and contribute to global warming. Carbon sequestration can be accomplished by biological, geological, or oceanic processes. In each case, the carbon sequestration activities may provide a variety of benefits in addition to sequestration; and similarly, activities may have carbon sequestration benefits in addition to their primary benefits.

In biological carbon sequestration processes, the amount of carbon taken up by and held in biological systems—i.e. by forests, grasslands, and other vegetation—is increased over that which occurs naturally. This could take the form of reforestation or afforestation, changing agricultural practices to increase soil carbon levels, and by other means. Benefits from forestry activities might include both increasing the amount of carbon sequestered in standing biomass and simultaneously providing habitat for a variety of wildlife and recreation for people. Benefits from agricultural activities might include both increasing the amount of carbon held in soils while potentially boosting agricultural productivity. Some aspects of biological sequestration are understood reasonably well, such as growing trees on deforested lands; further research can improve these efforts and significantly refine quantitative estimates of the sequestration potential. Other aspects, such as increasing forest or agricultural soil carbon levels, also need further research. Typical estimates of the amount of carbon sequestered in standing biomass and forest soils in the United States are in the range of 80 to 120 tons of carbon per acre. However, forest within the U.S. can vary widely depending on region and species composition (i.e., from less than 40 tons of carbon per acre in pinyon-juniper forests to over 240 tons per acre in the old-growth forests of the Pacific Northwest). Of the total carbon, about 30% is in the trees, 60% is in the soil, and 10% is on the forest floor and in understory vegetation, however, this is difficult to quantify precisely. The carbon in standing biomass, as well as much of the soil carbon, is sequestered over 40-70 years of growth for such species as loblolly pine and spruce, and considerably longer for undisturbed stands of old-growth species such as douglas fir. As a forest matures, the net carbon sequestration rate slows, even though the total amount of carbon stored in the forest may be quite great. The forest wood can be harvested and used to produce fuels such as ethanol, methanol, or Fischer-Tropsch liquids (a synthetic diesel substitute) for transport together with electricity, offsetting the use of fossil fuels and thus reducing total carbon emissions. If the area is then successfully reforested, the cycle can continue.

In geological processes, carbon dioxide is stored in deep underground geological formations. This approach requires developing technologies to capture and dispose of (or reuse) carbon dioxide from power plants or other central sources, coupled with developing technologies for sequestering the carbon dioxide in geological formations and analyzing the effects of high pressure carbon dioxide injection on the long term geomechanical and geochemical sequestration integrity of the formation. For example, much more research is needed to determine and minimize the costs of capturing and injecting carbon dioxide into deep geological structures. Even more important is understanding the impact this has on the geological formation itself. For example, extracting oil and/or gas from a geological formation may damage it, allowing the subsequent escape of carbon dioxide if it were stored there. Injecting carbon dioxide into a geological formation may lead to the formation of an acidic solution that would dissolve certain rocks or minerals allowing the escape of the carbon dioxide out of the formation and ultimately to the atmosphere. Estimates of the total potential carbon storage in depleted oil and gas wells range as high as 100 to 500 billion tons worldwide, although the fraction of this total in formations that would be stable with carbon dioxide injection or that could be cost-effectively tapped is not understood. Enhanced oil recovery using reservoir pressurization with carbon dioxide is currently being done at a number of sites and can result in the sequestration of carbon in the depleted oil reservoir. These activities may be undertaken for their own specific benefits independent of their potential carbon sequestration, but carry with them the added benefit of sequestration.

Carbon sequestration in underground saline aquifers has the potential to sequester, by some estimates, as much as 100 to 1000 billion tons of carbon. However, for long-term carbon storage (millennia), it may be necessary to use only those deep saline aquifers which have structural traps that can ensure the carbon will not escape to the atmosphere; this might limit the sequestration capacity to a few billion tons. In conclusion, the potential of geological sequestration is not well understood at this time, neither in terms of overall capacity or location of potentially usable geological structures, nor the requirements on those structures to ensure long-term isolation of the carbon dioxide.

In oceanic processes, carbon dioxide would be pumped into the ocean depths. Since atmospheric carbon dioxide levels have risen substantially from human activity in the past 100 years, ocean carbon dioxide levels are no longer in equilibrium with atmospheric levels and consequently the oceans are gradually absorbing some of this excess carbon in the atmosphere. Directly injecting carbon into the ocean would speed up this process of reaching a new equilibrium. Although the potential carbon capacity of the ocean is as high as 1000-10,000 billion of tons, the length of time this carbon would remain in the deep ocean is not well understood, nor how disposing of large quantities of carbon in the deep ocean would impact local ocean circulation patterns and ocean ecology. For these reasons, this potential remain highly uncertain.

Agencies that have active programs specifically focused on carbon sequestration activities include the Department of Energy and the Department of Agriculture. The Environmental Protection Agency has some related programs but no specific line-item funding for carbon sequestration.

The Department of Energy currently has a limited program within the Office of Fossil Energy, with funding of about $1.6 million in FY 1998 to develop and demonstrate technically, economically, and ecologically sound methods to capture, reuse and dispose of carbon dioxide through sequestration technologies. This program involves collaboration with 17 countries through the International Energy Agency Greenhouse Gas Program. In FY 1999, the Administration is proposing to expand the Fossil Energy program to about $12 million, with collaborative R&D on advanced technology for greenhouse gas separation, capture, storage (primarily geological) and reuse ($1.89 M); integration of fossil fuel production and use with natural sinks (e.g., biological) enhancement (this includes activities with the International Energy Agency Greenhouse Gas Program, Electric Power Research Institute, and others) ($2.5M); and on novel "path breaking" concepts for reducing greenhouse gas emissions ($7.5M).

The Department of Energy is also requesting $9 million in FY 1999 for the Energy Research budget to better understand the fundamental scientific aspects of carbon sequestration, including $4 million for fundamental research on biological capture, $2 million for research on ocean sequestration, and $3 million for geological sequestration research. These programs comprise the sequestration components of the Administration's $39 million request for carbon sequestration and crosscutting research within the Department of Energy; the other components of the $39 million are focused on fundamental science of efficient and of low-no carbon technologies. These programs will be coordinated closely with each other and with those of other agencies.

The Department of Agriculture has carbon offset and carbon sequestration related programs under the Agricultural Research Service, including the Biomass for Energy and Agricultural Industry Practices programs, and under the Forest Service, including biomass for energy and carbon sequestration. The FY1999 Budget Request for these and other activities is $7.5 million under the ongoing Climate Change Action Plan, with no change from FY 1998, and $10 million for the FY 1999 Climate Change Technology Initiative Activities. Specific to carbon sequestration are portions of: (1) Agricultural Industry Practices program which, among other activities, will examine practices to increase rates of sequestration of carbon in agricultural and forest soils; (2) Recycling Research, which will, among others, examine the potential for greater carbon sequestration through use of wood and fiber in structures; and (3) Forest Stewardship Incentive Program which provides for accelerated tree planting on non-industrial private forest lands, with carbon sequestration benefits, as well as protecting soils and providing numerous other benefits.

The Environmental Protection Agency has no line item funding for carbon sequestration work, but does have related programs to determine baseline emissions levels, identify mitigation opportunities, and estimate carbon coefficients for some land use systems. These activities are small portions of other ongoing activities not specific to carbon sequestration.

Additional information about these programs and their budgets is available from the Agencies.

Q2. Which agency is considered to be the lead agency on carbon sequestration research and development? Who is responsible for coordinating the different agencies' efforts on carbon sequestration?

A2. The different agencies have largely complementary activities, with, for example, DOE leading efforts on controlling emissions from the combustion of fossil fuels and conducting fundamental research in biological and geological processes for carbon sequestration, and the USDA and Forest Service leading efforts on agriculture, forest management, and soils. In addition, the EPA is estimating emissions coefficients for certain land-use changes. The agencies have coordinated their existing level of work on carbon sequestration through interagency teams as well as direct consultation. Activities to date have been so limited in scope that there has been little need for a detailed formal system of coordination and control. If the requested funding for further carbon sequestration work is approved, then more substantial inter-agency coordination would possibly be appropriate.

Q3. Describe the procedures used to evaluate individual agency programs and projects to ensure that the government-wide carbon sequestration research and development effort is comprehensive and not duplicative?

A3. To date, the Federal program has not been comprehensive and has been operating at a very low level of funding; that is why the FY 1999 Budget Request proposes enhancing these efforts. The President's Committee of Advisors on Science and Technology (PCAST) Energy R&D Panel recently stated "*The current annual funding level* (for carbon sequestration) *in FE* (Fossil Energy Program) *is insufficient. It should be increased to a level in the range of several tens of millions ...* " PCAST did not review the DOE Basic Energy Sciences Program to make recommendations on the fundamental science of carbon sequestration, nor did it review programs at USDA or EPA. As for other Federal programs, intra- and inter-agency coordination and review mechanisms are employed to ensure effective use of funds.

The DOE programs are coordinated within and between the Fossil Energy Program and the Energy Research program, each focusing on complementary activities. The USDA has recently established a Global Change Program Office to: provide leadership in planning, coordinating, analyzing, and reviewing various USDA climate change programs; identify new research initiatives; provide liaison with and support to executive branch, members of Congress, and the customers of the USDA affected by global change and related activities. The EPA's activities are coordinated with USDA and DOE efforts.

Q4. Carbon sequestration was an activity being pursued under the old Climate Change Action Plan as one of the voluntary measures that would limit growth in net carbon emissions. What percent reduction of our current annual net carbon emissions from fossil fuel combustion might we expect to achieve through carbon sequestration measures?

A4. There appears to be a potentially significant opportunity to reduce or offset net carbon emissions through both biologically and geologically based carbon sequestration efforts. However, much more research is needed to determine the magnitude of the opportunity and the potential costs. If successful, such approaches may assist the continued use of fossil fuels even in a greenhouse gas constrained world.

On the biological side, the U.S. Climate Change Action Plan (CCAP) identifies tree planting as the main opportunity to sequester carbon. CCAP was designed to sequester 10 million metric tonnes of carbon through enhanced forest growth and related measures. Due to funding cuts, the primary sequestration will be through Action 44 to Accelerate Tree Planting in Nonindustrial Private Forests; this action is expected to sequester 2.2 million metric tons of carbon by 2010. Further details can be found in the 1997 Climate Action Report, Department of State publication #10496.

Opportunities for further sequestering carbon in agriculture could include the conversion of marginal cropland and pasture to forest and promoting the use of management practices that increase the quantity of carbon stored in agricultural soils. Such actions would also potentially provide a number of other benefits including better runoff and erosion control, improved habitat, and many others. Studies suggest that these sinks could technically offset a significant amount for U.S. GHG emissions—for example, under question 1 it was estimated that reforestation of 1 million acres sequesters roughly 40 million tons of carbon in standing biomass over perhaps 50 years, or roughly 0.8 million tons per million acres per year. This amount, 0.8 million tons per year, can be compared to current U.S. emissions of 1,500 million metric tons per year. Planting about 19 million acres, then, would offset about 1 percent of U.S. emissions, or 15 million tons of carbon per year during the growth of these trees. The Congressional Office of Technology Assessment estimated potential reductions in 2015 (estimated in 1990 and based on 1987 U.S. emissions) of 0.2 to 6.3 percent of U.S. carbon emissions (not including use as a fossil fuel offset). Economic analysis of such possibilities is limited and requires further research.

On the geological and oceanic side, various estimates have been made of the sequestration potential in depleted oil and gas wells, deep saline aquifers with and without structural traps, and the ocean, as indicated above. Estimates of the global sequestration potential run as high as 100-500 billion tons of carbon in depleted oil and gas reservoirs; 100-1000 billion tons in deep saline aquifers, and 1000 to 10,000 billion tons in the ocean; practical potentials will be much less. This can be compared to global carbon emissions of roughly 5-6 billion tons per year and to U.S. carbon emissions of 1.4 billion tons per year. Without further research into the practical carbon sequestration capacity of these biological, geological, or oceanic processes; their structural integrity and/or lifetime for storage of the carbon; the location of the potential sequestering reservoir (versus the location of the carbon which one wants to sequester), and the costs of sequestration, the actual potential and costs are speculative at this time.

COMMITTEE ON SCIENCE
U.S. HOUSE OF REPRESENTATIVES

Hearing
on

The Road from Kyoto—Part 2:

Kyoto and the Administration's Fiscal Year 1999 Budget Request

Thursday, February 12, 1998

Post-Hearing Questions
Submitted to

The Honorable Ernest J. Moniz
Under Secretary of Energy
U.S. Department of Energy

Post-Hearing Questions Submitted by Chairman Sensenbrenner

"Enhanced Energy R&D Investments Provided for in DOE's FY 1999 Budget Request Will Indeed Result in Lower Greenhouse Gas Emissions"

Q1. On page 1 of your testimony, you state that "The enhanced energy R&D investments provided for in DOE's FY 1999 budget request will indeed result in lower greenhouse gas emissions"

Please provide documentation of the lower greenhouse gas emissions that will result from these "enhanced energy R&D investments provided for in DOE's FY 1999 budget request."

A1. Attached are pages 309-310 of the President's FY 1999 budget request for Interior Appropriations. These tables provide project energy, economic and environmental savings from the Office of Energy Efficiency and Renewable Energy Programs in Transportation, Industry and Buildings and the Federal Energy Management Program.

The following overview summarizes the program's projected benefits, sector activities, cross-cutting programs, and regional support office responsibilities. Each sector description provides information on new activities for FY 1999, projects to be discontinued or completed in FY 1998 and FY 1999, and ongoing programs.

EERE PROGRAM BENEFITS

EERE's research, development and deployment of energy technologies have led to billions of dollars in energy cost savings over the past decade. Over the next 25 years, there will be significant additional benefits associated with each sector's programs, including increased energy efficiency, and associated cost savings and emissions reductions.

Projected energy, economic, and environmental savings are presented in the following table. *Total Primary Energy Displaced* refers to the amount of conventional, fossil, or electric energy directly displaced through energy efficiency improvements. One quadrillion BTUs has the energy equivalent of 172 million barrels of oil. *Energy Cost Savings* represents the annual dollar savings that consumers will realize through reduced energy consumption. Finally, the carbon figures represent the amount of carbon equivalent emissions that will be avoided due to reduced energy consumption. EERE uses carbon reductions because in many applications they serve as a useful measure and surrogate for a wide variety of energy-related pollutants, including carbon monoxide (CO), nitrogen oxides (NO_x), sulfur oxides (SO_x), particulates, and in some cases, heavy metals.

Office of Energy Efficiency and Renewable Energy
Energy Efficiency Programs Projected Annual Benefits by Sector through the Year 2020

	Total Primary Energy Displaced (Quadrillion BTUs)			Energy Cost Savings ($ billions)			Carbon Reductions (million metric tons)		
	2000	2010	2020	2000	2010	2020	2000	2010	2020
Transportation Sector *(oil savings in quads)*	0-.01 *(.07-.13)*	.93-1.23 *(1.33-2.40)*	2.49-2.74 *(3.05-4.17)*	0-.49	7.57-9.68	15.5-20.54	.3-.64	17.9-26.66	47-55.17

	Total Primary Energy Displaced (Quadrillion BTUs)			Energy Cost Savings ($ billions)			Carbon Reductions (million metric tons)		
	2000	2010	2020	2000	2010	2020	2000	2010	2020
Industry Sector	.15-0.27	.95-1.46	1.52-2.47	.58-1.03	3.06-4.65	4.79-7.72	2.3-5.39	16.5-30.74	31.8-51.63
Building Technology, State & Community Sector	.07-.07	1.41-2.04	2.8-5.46	0.50-0.50	9.77-14.13	18.63-36.34	1.1-1.45	22.4-44.86	47.2-120.1
Federal Energy Management Program	.06	.24	.31	.42	1.41	1.92	1.16	4.4	5.63

Note: The program benefit ranges are developed through an impact analysis process undertaken annually by the Office of Energy Efficiency and Renewable Energy (EERE). The upper point of each range is based on analysis conducted by EERE's sectors and externally reviewed by Arthur D. Little. The sectors analyze the impacts their programs will have on energy savings, cost savings, and carbon reductions if all program goals are met. The lower point of each range for energy displaced and carbon reductions is derived from an integrated analysis model run by external contractors that controls for interaction effects. The integrated analysis model accounts for inter- and intra-sector double-counting as well as market trends, including reductions in new electricity generation. The lower point of the energy cost savings range is calculated by multiplying the total primary energy displaced, derived from the integrated analysis, by the sector's energy cost savings/total primary energy displaced ratio for that year.

1997 R&D 100 Awards

Q2. On page 1 of your testimony, you also state that "The success of this system over many years, and its importance to American society in the future, is highlighted by the prestigious *1997 R&D 100 Awards*, no fewer than 36 of which went to DOE supported work."

Q2.1 Please provide a listing and description of each of these 36 *1997 R&D 100 Awards.*

A2.1 Described below are the Department's 36 1997 R&D 100 Awards:

1. Alloys for improved permanent magnets that could be used in more energy efficient motors (Ames Laboratory, Idaho National Environmental Engineering Laboratory)

2. An electrophoresis DNA sequencer that decodes genetic information more than 20 times faster than current machines, making it cheaper and faster to do research (Ames Laboratory)

3. A process to convert corn into a cost-effective, environmentally friendly source of chemicals that can be used to make industrial products including polymers, paints, inks and clothing fibers (Argonne National Laboratory, National Renewable Energy Laboratory, Oak Ridge National Laboratory, Pacific Northwest National Laboratory)

4. A mass spectrometer/analyzer that makes it possible to markedly improve materials' properties and manufacturing processes in the semiconductor and electronic industries (Argonne National Laboratory)

5. A significantly improved fluorescence detector for biological research that can characterize up to 50,000 photons per second (Brookhaven National Laboratory)

6. A device that will enable investigators to measure underground water movement more accurately and deeper than ever before (Idaho National Environmental Engineering Laboratory)

7. A diagnostic method for in-field analysis of degrading concrete that can identify problems in roads and bridges before extensive repairs become the only remediation option (Los Alamos National Laboratory)

8. Improved software to model large oil and gas reservoirs that cannot be modeled with present-day simulators and thus greatly enhance oil and gas recovery (Los Alamos National Laboratory)

9. A fast and environmentally friendly dry-cleaning process that can replace existing hazardous processes (Los Alamos National Laboratory)

10. A plasma source ion implantation process that makes metallic parts used in automobiles, airplanes, machine tools and prosthetic devices more durable without hazardous waste by-products (Los Alamos National Laboratory)

11. A technique to identify genetic mutations by analyzing much larger DNA fragments than present-day techniques (Los Alamos National Laboratory)

12. A high performance software storage system which has significantly more capacity and speed than others (Los Alamos National Laboratory, Lawrence Livermore National Laboratory, Oak Ridge National Laboratory, Sandia National Laboratory)

13. A new plasma source for materials synthesis that enables films to be deposited at greatly increased rates with minimal surface damage (Lawrence Berkeley National Laboratory)

14. A revolutionary laser cutting and machining tool that removes material atom by atom and can precisely machine everything from steel to soft materials such as heart tissue (Lawrence Livermore National Laboratory)

15. A new insulator that withstands voltages four times higher than conventional insulators that will improve x-ray machines and microwave generators (Lawrence Livermore National Laboratory)

16. A device which identifies optimal oil-well drilling sites to depths never achieved (Lawrence Livermore National Laboratory)

17. An ultra-clean ion beam system with accuracy close to the size of a single atom that can advance the production of computer chips (Lawrence Livermore National Laboratory)

18. Software for computer simulation essential to the design of new micro-optic electronic devices (Lawrence Livermore National Laboratory)

19. An interferometer which can measure surface shapes with a one hundred-fold improvement over current methods (Lawrence Livermore National Laboratory)

20. Software allowing improved optical modeling and design of solar cells (National Renewable Energy Laboratory)

21. A commercial microwave heating system for research and manufacturing applications which provides controlled, uniform temperatures not possible with conventional heating and traditional microwave systems (Oak Ridge National Laboratory)

22. A device for detecting occupants concealed in a vehicle or enclosed space to foil smuggling and terrorist activity (Oak Ridge National Laboratory, Y-12)

23. A carbon-free crucible for melting metal by induction heating which dramatically reduces contamination (Oak Ridge National Laboratory, Y-12)

24. A system to produce the radioisotope technetium-99m for medical use that is environmentally cleaner, safer and half the cost of current techniques (Oak Ridge National Laboratory)

25. Epoxy resins that can be cured in seconds using electron beam radiation that can replace existing thermally cured epoxies which require harmful chemical hardeners and hours to process (Oak Ridge National Laboratory)

26. A low cost, more effective sorbent for environmental sampling of organics in air (Oak Ridge National Laboratory)

27. A technique to manufacture pore-free, cast aluminum components for automobiles with properties close to those of forgings, at a third of the cost of forged parts (Oak Ridge National Laboratory)

28. A device to monitor corrosion of refractory insulation in high-temperature furnaces during operation; this will improve productivity and minimize the downtime for inspection (Pacific Northwest National Laboratory)

29. A technology using microorganisms to help recycle waste automobile tires (Pacific Northwest National Laboratory)

30. A system to mitigate the effects of factory-wide power disturbances on electric equipment with the potential to save billions of dollars annually in production costs (Sandia National Laboratory)

31. A more precise method of setting off explosives for seismic exploration which provides better data from return echoes (Sandia National Laboratory)

32. A software library of equation solvers for supercomputers which allows more efficient solution of scientific computing problems (Sandia National Laboratory)

33. A method to control induction heating processes for automobile parts so that scrap losses are eliminated (Sandia National Laboratory)

34. An optical probe to measure growth rates in thin film production of microelectronic components which allows improved manufacturing efficiency (Sandia National Laboratory)

35. A handheld biological microcavity laser device which analyzes blood samples in minutes, without the time and cost of shipping to a lab for analysis (Sandia National Laboratory)

36. A new transistor device which avoids loss of data when computers experience an unexpected power outage (Sandia National Laboratory)

Q2.2 How many applications did DOE-supported work submit for the *1997 R&D 100 Awards*?

A2.2 R&D Magazine estimates that 120-140 applications were submitted for DOE-supported work in the 1997 award cycle.

Q2.3 Please describe the process of applying for the *R&D 100 Awards.*

A2.3 R&D Magazine has established a formal process for the annual competition. An entry form is posted on the magazine's web site. Applications are due this year on March 24, 1998. The applicant, following the entry form format, describes the new technical product or process.

Q2.4 Please provide documentation of the funds expended for all DOE-supported work applying for the *1997 R&D 100 Awards.*

A2.4 There is a $150.00 entry fee for each application submitted. The magazine, based on experience, estimates that it takes 20-40 hours of effort by each applicant to put the requested information together.

U.S. Energy Expenditures

Q3. On page 2 of your testimony, you state that "United States expenditures for energy now top $500 *billion* annually, accounting for over 7.5 percent of our gross domestic product (GDP). The annual electricity bill for American consumers is roughly $200 billion and the cost of energy for U.S. manufacturing industries alone stands at $100 billion per year."

Please document these statements.

A3. The above statistics are from two Energy Information Administration publications: the Annual Energy Review 1996 (AER96) and the State Energy Price and Expenditure Report 1994 (SEPER94).

The number $500 billion came from Table 3.4 of AER96. The number 7.5 percent was calculated using statistics from Table 3.4 and Table D1 of AER96. The number $200 billion came from Table 3.4 of AER96. The number $100 billion came from Table 8 of SEPER94.

U.S. Energy Use Per Dollar of GNP

Q4. On page 2 of your testimony, you also state that "The United States decreased its energy use per dollar of GDP by 30 percent between 1975 and 1986, in essence representing an annual energy savings today of over $170 billion. Despite this track record, the energy intensity of the U.S. economy is 50 percent higher than that of other industrialized nations and the potential for increased energy efficiencies in the U.S. economy remains considerable."

Please document these statements.

A4. The above statistics are derived from the Annual Energy Review 1996 (AER96) and International Energy Annual 1996 (IEA96).

The number 30 percent was calculated from the energy to GDP ratio (E/GDP) reported in Table 1.6 of AER96.

The number $170 billion is calculated based on statistics from Table 1.6, Table 3.3, and Table D1 of AER96.

1986 GDP * 1975 (E/GDP) = estimated 1986 energy consumption without efficiency improvement (1986 E_{woei}.)

Annual savings = $(1986E_{woei}$ -1986 $E_{actual})$ * (1986 Average energy price) * (implicit price deflator)

The number 50 percent is derived from Table B2 and Table E1 of IEA 96. Table B2 reports World Gross Domestic Product at Market Exchange Rates. Table E1 reports World Primary Energy Consumption. Energy intensity (E/GDP) is calculated for major industrialized countries and then compared with the US energy intensity. For the U.S., the E/GDP ratio in 1996 is 16.67 (in 1987$), which is more than 50 percent higher than the average for the major industrialized countries of 9.57 (in 1987$).

Global Market for Energy Supply Equipment

Q5. On page 2 of your testimony, you also state that "The global market for energy supply equipment is about $300 billion annually."

Please document this statement.

A5. The $300 billion annually is a round (ballpark) number constructed from information contained in several sources. If anything, the $300 billion annually could be conservative since it doesn't include ships (tankers, bulk coal carriers), refineries, local distribution networks for natural gas and electricity, non-grid connected renewable energy supplies, and nuclear fuel cycle costs (including waste management costs). The principal sources used to construct this number include:

- National Energy Strategy, Technical Annex 5, "Analysis of Options to Increase Exports of U.S. Energy Technology", U.S. Department of Energy, 1991/92
- Sustainable Energy Strategy, National Energy Policy Plan, U.S. Department of Energy, July 1995.
- The Global Power Market: Trends and Projections, 1994-2010, Solomon Brothers Research Report, August 24, 1994.
- World Energy Outlook, International Energy Agency, Paris, France, 1995 and 1996 editions.
- Financing Worldwide Electric Power: Can Capital Markets do the Job? Resource Dynamics Corporation Report to the U.S. Department of Energy, April, 1996.

<u>Projections for Global Energy Use and Implications for Global Carbon Emissions</u>

Q6. Finally, on page 2 of your testimony, you state that "The world will likely double its energy use by 2030 and quadruple its use by the end of the next century. Oil demand is projected to grow by about two percent annually over the next 20 years. Total world energy consumption is projected to reach 560 quadrillion Btu in 2015, an increase of 200 quadrillion Btu over 1995 totals."

What are the implications of these global energy use projections for global carbon emissions?

A6. According to the projection reported in Table A9 of the International Energy Outlook 1997 (IEO97), world total carbon emissions are projected to reach 9704 million metric tons in 2015, an increase of about 3463 million metric tons over 1995 level.

Longer term carbon emissions depend on prices of fuels and technical progress in energy consuming technologies. Given the demand for total energy, a mix with low carbon fuels will have lower carbon emission than otherwise.

<u>Projection of DOE's Current Oil and Gas Program to Stimulate Additional Liquids Projection</u>

Q7. On page 2 of your testimony, you state that "The Department's current oil and gas program is projected to stimulate about 1,000,000 barrels per day of additional liquids production by 2010."

Please document this statement.

A7. The estimated 1,000,000 barrels per day of additional liquids results from activities being pursued and planned under two distinct efforts, the Oil Program and the Gas-to-Liquids Program. The Oil Program activities are estimated to contribute 800,000 barrels of oil per day and the Gas-to-Liquids Program is estimated to contribute 200,000 barrels of liquids per day in 2010.

These estimates were developed by the Fossil Energy Oil and Gas Analysis Team. The work of this team focuses on developing, evaluating, and improving the analytical capabilities of the Department in order to assess the benefits of the its investment in oil and gas research and development activities. One measure of the program's effectiveness is the impact on future domestic oil and gas production.

Analysis of the Oil Program activities, such as advanced imaging, drilling, production and environmental activities, were conducted primarily using the Total Oil Recovery Information System model (TORIS), the Change, Resource, Impact, Probability System (CRIP), and the Crude Oil Policy Model (COPM). Using TORIS, CRIP and COPM, two scenarios were developed: one that included the DOE Oil Program and one without the DOE Oil Program. The resulting domestic oil production from each scenario was compared and showed that the DOE Oil Program would stimulate the production of an additional 800,000 barrels of oil per day.

The Gas-to-Liquids (GTL) Program activities were analyzed using the analysis and information contained in the DOE sponsored study entitled, "Economics of Alaska North Slope Gas Utilization Options,"dated August 1996, and conducted by the Idaho National Engineering Laboratory. We expect North Slope gas from Prudhoe Bay, Point Thompson and/or other reservoirs to be available to the market in the 2005-7 time frame. Our program would provide a technology option to convert this gas to liquids in GTL plants of economic scale near the Trans Alaska Pipeline System intake at Prudhoe Bay by 2010. The aggregate production volume is estimated to be 200,000 barrels per day of distillate and other hydrocarbon liquids.

Revolutionary Ceramic Membrane

Q8. On page 5 of your testimony, you state that "Last year, DOE initiated a cost-shared, joint government-industry collaboration to produce a revolutionary ceramic membrane that might significantly lower the cost of chemically converting natural gas into a middle distillate liquid. Such a breakthrough in the current limitations that transportation places on natural gas could add a billion barrels or more of vital liquids to our energy supply."

Q8.1 Please elaborate on this government-industry collaboration.

A8.1 In May 1997, the Department of Energy (DOE) selected an industry/DOE National Laboratory team headed by Air Products and Chemicals Inc. (APCI) to develop a novel ceramic membrane, one that would allow oxygen ions to pass from air on one side to the other where the ions would react with natural gas (methane) to form a "syngas" composed of carbon monoxide and hydrogen. This syngas, after adjustments to secure a precise ratio of the two compounds, can be subsequently converted to a variety of liquid transportation fuels and petrochemicals. The reference to "revolutionary" pertains to the separation of oxygen and the partial oxidation of the methane accomplished in one single step. Current state-of-the-art conversion technology calls for a separate oxygen making plant and a separate syngas reactor. The elimination of the oxygen plant requirements and the single-step membrane reactor could save upwards of 25% or more of presently projected conversion costs. The key to this will be the unique composition of the ceramic membrane, how well it passes oxygen, and how well it (together with its connections to piping) handles stresses brought about by operation in the 900-1,000 degree C temperature range.

In September 1997, an $85 million, provisional cooperative agreement was awarded to APCI for an eight-year effort to be done in three phases. Cost-sharing will be approximately 35% DOE and 65% APCI. In addition, if this membrane is successful and commercialized, APCI will reimburse DOE for its outlay by dedicating a portion of its proceeds of membrane-derived sales to repay to the Federal government the $30 million DOE contract share.

Q8.2 Please document the statement that "Such a breakthrough in the current limitations that transportation places on natural gas could add a billion barrels or more of vital liquids to our energy supply."

8.2 An economic analysis prepared by DOE's Idaho National Engineering (and Environment) Laboratory (INEL) projected that two of Alaska's major reservoirs on its North Slope, Prudhoe Bay and Point Thompson, could have approximately 25 trillion cubic feet of natural gas available for gas-to-liquids conversion in the future. Because of the remote location of the North Slope from gas markets, the gas is currently without a market, and even to convert to Liquefied Natural Gas (LNG) for ocean transport to Asia (as proposed) would require construction of an 800-mile gas pipeline to an LNG plant and shipping point. The analysis indicated that gas could be converted to hydrocarbon liquids at the North Slope, which then could be shipped 800 miles through the Trans Alaska Pipeline System (TAPS) with the North Slope's remaining crude oil production. Utilization of this technology, if successful, could add a billion barrels or more of liquids to our energy supply.

FY 1999 Budget Request for Building Technologies

Q9. On page 6 of your testimony, you state that "The FY 1999 budget request for building technologies of $317 million will result in substantial R&D progress on a wide range of technologies including high-efficiency heat pumps, advanced lighting, fuel cells, insulation materials and intelligent control systems."

Please provide a breakdown of how much of the $317 million request is for research, how much is for development, and how much is for commercialization.

A9. The $317 million request for Building Technology, State and Community programs includes a request of $198 million for state and local partnership grants including $5 million for competitive energy partnerships and $23 million for non-R&D codes and standards and management. The FY 1999 budget request directs $37.0 million for applied research, $34 million for development and $31 million for technology access excluding formula grants. Included are several pre-commercial deployment activities including Rebuild America, community partnerships and Energy Star labelling. The Buildings program has not requested any funds for basic research.

The research proposals include component research for lighting, envelope research that includes insulation and windows, space conditioning and cogeneration that includes heat pumps, desiccants and chillers, and fuels cells. It also includes $8 million in a competitive research solicitation that affords us the opportunity to focus on proposals resulting from the technology road maps. Development funds are spread across most of the programs that are developing prototypes and new processes to meet specific requirements such as Building America, design tools and industrialized housing.

Technology access supports technical assistance, training and deployment activities such as Rebuild America and the Energy Star programs.

FY 1999 Budget Request for Industrial Technologies

Q10. On page 6 of your testimony, you also state that "The FY 1999 budget request for industrial technologies of $167 million will result in substantial R&D progress on a wide range of industrial technologies in areas such as aluminum production, waste reduction, combustion efficiency, biomass feedstock use, glass smelting and industrial cogeneration."

Please provide a breakdown of how much of the $167 million request is for research, how much is for development, and how much is for commercialization.

A10. Of the FY 1999 request, approximately $27 million will be spent on applied research, and approximately $130 million will be spent on development; the balance of $9 million is program direction. As you may know, there are differing definitions of research, development, and commercialization. We do, in the course of development, support training, pilot demonstrations, and related activities to help ensure that technologies under development will become commercialized. We believe, however, that commercialization itself consists of financial subsidies to encourage entry into the marketplace, and none of the requested funding is for such commercialization activities.

FY 1999 Budget Request for Transportation Technologies

Q11. On page 6 of your testimony, you also state that "The FY 1999 budget request for transportation technologies of $293 million will result in substantial R&D progress not only for the PNGV auto; it also will focus increased effort on developing technologies that substantially improve the efficiency of light trucks and sport utility vehicles, the fastest growing transportation segment. It will allow for significant progress toward improving heavy truck fuel economy from 6-7 mpg now to 10 mpg."

Q11.1 Please provide a breakdown of how much of the $293 million request is for research, how much is for development, and how much is for commercialization.

Q11.1 Of the $293 million requested for transportation technologies, it is estimated that $76 million will be used for research, $192 million will support development activities, $16 million will be directed toward technology demonstrations, and $9 million will be used for program management.

Q11.2 Please provide a detailed breakdown of the FY 1997 actual, the FY 1998 estimated, and the FY 1999 budget request for PNGV.

Q11.2 The following table shows funding that supports work directly relevant to PNGV and coordinated with PNGV technical teams:

(dollars in millions)

PROGRAM	FY 1997 Actual	FY 1998 Estimated	FY 1999 Request
Department of Energy			
Office of Transportation Technologies			
Automotive Alternative Fuels			
Systems Optimization	0	4.7	6.0
Engineering Competitions	0	0.9	1.0
Vehicle Systems R&D			
Hybrid Propulsion Systems	38.0	44.7	25.0
Heat Engine R&D	4.8	0	13.0
High Power Energy Storage	8.0	9.0	15.0
Advanced Power Electronics	3.0	4.5	5.0
Fuel Cell R&D			
Systems Development	11.8	4.1	7.5
Component R&D	4.5	11.1	18.1
Reformer & Storage R&D	4.5	8.3	19.0
Advanced Combustion Engine R&D	7.5	7.6	18.0
Cooperative Automotive Research for Advanced Technologies	0	0	6.0
Automotive Materials Technology			
Propulsion System Materials	6.4	6.5	3.0
Lightweight Vehicle Materials	13.6	15.3	16.0
Office of Industrial Technologies			
Industries of the Future (Specific)			
Aluminum Vision (Spray Form)	1.0	1.0	1.0
Office of Energy Research	6.5	5	5
Office of Defense Programs	0.9	0	0
Subtotal, Department of Energy	**110.5**	**117.7**	**153.6**
Department of Commerce	0.5	0.5	0.5
Department of Transportation	2.5	4.5	4.0
Environmental Protection Agency	12.9	17.0	35.0
TOTAL FEDERAL PNGV	**126.4**	**139.7**	**193.1**

<u>FY 1999 Budget Request for Transportation Technologies</u>

Q12. On page 6 of your testimony, you also state that "The FY 1999 budget request for transportation technologies of $293 million will result in substantial R&D progress not only for the PNGV auto; it also will focus increased effort on developing technologies that substantially improve the efficiency of light trucks and sport utility vehicles, the fastest growing transportation segment. It will allow for significant progress toward improving heavy truck fuel economy from 6-7 mpg now to 10 mpg."

Q12.1 Please provide a breakdown of how much of the $293 million request is for research, how much is for development, and how much is for commercialization.

Q12.2 Please provide a detailed breakdown of the FY 1997 actual, the FY 1998 estimated, and the FY 1999 budget request for PNGV.

<u>FY 1999 Budget Request for Renewable Energy Technologies</u>

Q13. On page 8 of your testimony, you state that "The FY 1999 budget request for renewable energy technologies of $342 million (excluding transportation biofuels) will result in substantial R&D progress that will make several technologies competitive in the marketplace in the very near term."

Please provide a breakdown of how much of the $342 million request is for research, how much is for development, and how much is for commercialization.

A13. DOE would not provide an answer to this question in spite of repeated requests.

Q14. On page 6 of your testimony, you state that "The FY 1999 budget request for building technologies of $317 million will result in substantial R&D progress on a wide range of technologies including high-efficiency heat pumps, advanced lighting, fuel cells, insulation materials and intelligent control systems."

Please provide a breakdown of how much of the $317 million request is for research, how much is for development, and how much is for commercialization.

A14. For answer see the response provided for question 9. (Duplicate question)

<u>Appropriate Government Role</u>

Q15. On page 12 of your testimony, you state that DOE's "overall technology strategy involves extensive work with private sector partners to assure that our programs are relevant, the government role is appropriate and that a payoff is in sight." How do you define the term "appropriate government role"?

<u>Consistency with the PCAST Recommendations</u>

Q16. On page 13 of your testimony, you state that "Our FY 1999 budget request is broadly consistent with the PCAST recommendations, both in overall resources and R&D priorities."

What the inconsistencies between your FY 1999 budget request and the PCAST recommendations?

A16. The thrust of the FY 1999 budget request for energy efficiency and renewable energy technologies is consistent with the PCAT recommendations. That is, the request reflects increased funding in those areas recommended by the panel. The major inconsistency is that the funding levels in the request are lower than those in the PCAST report—due to the Administration's goal of presenting a responsible budget in a fiscally constrained environment. However, within that environment, the Department has increased the funding request for programs and technologies that the PCAT regards as most critical.

<u>DOE R&D Council</u>

Q17. On page 13 of your testimony, you also discuss the DOE R&D Council and state that "The Council, which I now chair, has a new charter, to more fully integrate and manage the Department's R&D both within and across program areas."

Q17.1 What is the R&D Council's new charter and how does it differ from the previous charter?

A17.1 The charter for the DOE R&D Council is attached **[NOTE: DOE would not provide this charter in spite of repeated requests.]** It differs in two important ways from the previous charter. First, the Council is much more focused on the leadership of the department. The chairmanship has been elevated to the Under Secretary, and the active involvement of program secretarial officers (PSOs) with substantial R&D budgets is now the norm.

The second important difference is the establishment of three working groups. The National Security R&D, Environmental Quality R&D, and Energy R&D Working Groups are organized to integrate and leverage the science and technology capabilities of the Department within and across business lines. The working groups are also chaired by the Under secretary, and include the relevant PSOs.

These two changes allow the R&D Council, and the Department, to do a much better job of integrating R&D efforts across program areas. The Council will provide a systematic basis for improving the linkage between basic and applied research, evaluating the alignment of R&D programs with department and national missions in the preparation of budgets, and advising and framing issues for the Secretary and Deputy Secretary.

The Council meets quarterly, and each working group meets monthly.

Q17.2 Please provide a list of the members of the DOE R&D Council, a listing of the DOE R&D Council's Working Groups and members of those Working Groups.

A17.2 *Membership.* The members of the R&D Council are the following Program Secretarial Officers: Energy research (ER), Defense Programs (DP), Energy Efficiency and Renewable Energy (EE), Environmental Management (EM), Fossil Energy (FE), Fissile Materials Disposition (MD), Nuclear Energy Science and Technology (NE), Nonproliferation and National Security (NN), and Civilian Radioactive Waste management (RW).

The working groups and their memberships are as follows:

National Security R&D:	DP. NN, MD, NE, ER
Environmental Quality R&D:	EM, RW, ER
Energy R&D:	EE, FE, NE, ER

Competing the M&O Contract for the National Renewable Energy Laboratory

Q18. On page 14 of your testimony, you note that DOE is in the process of competing the M&O contract for the National Renewable Energy Laboratory in Colorado.

What is schedule for competing and awarding the M&O Contract for the National Renewable Energy Laboratory?

A18. A competitive procurement was recently completed. Midwest Research Institute was selected as the contractor and award of the successor Performance-Based Management Contract occurred on November 9, 1998.

Updating the Way DOE Selects R&D Performers

Q19. On page 14 of your testimony, you state that "We will be intensifying our evaluation of how we award grants and contracts, including technology transfer and partnership agreements, to ensure they are made on the basis of sound scientific review and economic judgment. We need to constantly evaluate the appropriateness of these agreements on a case-by-case basis and make policy and process adjustments when necessary."

Please describe the process(es) you will be using to intensify your evaluation of how you award grants and contracts, including technology transfer and partnership agreements, and how this differs from your current process(es).

A19. The Under Secretary, under the auspices of the R&D Council, is undertaking a review of the procedures used by each program to award grants and contracts. This review will, in particular, consider the important role of peer review, and the adequacy of competition in the making of awards. The review will be used to identify any weaknesses or inconsistencies in the procedures used by each of the programs. The Under Secretary will work with the management of each program to assist them, if needed, in strengthening their procedures.

The Under Secretary, again under the auspices of the R&D Council, has initiated a review of DOE's policies on and implementation of partnerships. This review will also include the active participation of the Laboratory Directors.

<u>Science and Technology "Roadmaps"</u>

Q20. On pages 14 and 15 of your testimony, you discuss science and technology "roadmaps".

Please describe the process(es) you will using to develop these science and technology "roadmaps".

A20. Technology roadmaps address specific scientific and technical problems by defining goals, engaging in a consensus building process with R&D performers and stakeholders, and developing R&D plans most likely to achieve success. They will be used to establish clear linkages between DOE missions, the programs designed to accomplish those missions, the technologies and knowledge required to make those programs successful, and the specific R&D programs or tasks required to produce those technologies. The roadmaps will be developed along and across the Department's business lines under the guidance of the R&D Council and its Working Groups. Technology roadmaps will serve as a primary tool with which to "strategically manage" the crosscutting R&D needs and capabilities of the Department.

There are three types of roadmaps that will support the program development and resource allocation process: R&D Program Plans, Strategic Mission Roadmaps, and Enabling Technology Roadmaps.

An R&D Program Plan is a "roadmap" that will be prepared annually by each program. These plans will articulate a set of goals and objectives that support the larger missions and goals of the Department, as agreed to by the Under Secretary and the R&D Council. Each R&D Program Plan will show the connection between -- provide a roadmap for -- the program area's mission, the programs established to accomplish that mission, the science and technology barriers to accomplishing the programs, and the R&D projects and tasks required to overcome those barriers. Each will also identify the key performers among the national laboratories, academia, and industry. Each R&D Program Plan will show how the program area intends to contribute to and benefit from Strategic Mission Roadmaps and Enabling Technology Roadmaps.

A Strategic Mission Roadmap is prepared annually for each of the critical R&D missions that comprise DOE's highest level corporate commitments. Two examples are Clean Power and Genomics. The accomplishment of these missions represent important goals for the Department and the country. The end result is thus important in its own right, not simply as a tool for accomplishing other R&D objectives.

Enabling Technology Roadmaps provide integrated plans for the development of technologies that are necessary for the accomplishment of some larger DOE mission--they "enable" the accomplishment of some larger goal(s). Examples include robotics, strategic simulation, materials, and major science facilities. Enabling technologies are often required by more than one program area. These roadmaps will describe the technical goals and milestones to be met and the areas of strength in the DOE R&D enterprise of laboratories and other performers which will be employed.

<u>FY 1999 Budget Request for the Million Solar Roofs Initiative</u>

Q21. The President's tax credit proposal includes $160 million over five years for rooftop solar equipment. Rooftop solar water heating systems have been around for many years and rooftop photovoltaic systems are already in the market. Given the fact that these systems are both available and will have a tax credit, why is DOE proposing what appears to be at least $10 million in the Solar Energy R&D budget for the Initiative? Why is this a wise use of scarce R&D funds?

A21. The DOE FY 99 budget request includes $6.4 million in the Photovoltaic Program for the Million Solar Roofs Initiative. While certain solar technologies are available commercially, they are not familiar products and their performance characteristics and benefits are not generally recognized. Solar panels are not a common part of equipment installed by builders of residences and commercial establishments. Available solar handbooks are not generally found in technical libraries of individuals and firms that design homes and buildings. Bankers, mortgage firms, and others involved in financing of residences have little or no experience with solar "extras" that may be part of a mortgage package. The "secondary" mortgage market of FHA, Fannie Mae, and Freddie Mac are similarly inexperienced. Most electric utilities, who would be directly involved when privately owned PV arrays deliver excess electricity back into the grid, have not established procedures for intertie equipment performance or safety, or for net billing. Despite commercial solar equipment offerings, solar building integration will not experience significant growth until solar technologies become mainstream topics for key players in the design, construction, and financing of residences and buildings and for managers of electric utilities.

The Million Solar Roofs Initiative is designed to address these shortcomings. Steps are planned to fill the information and knowledge gaps of key participants. Alliances will be made with local governments and other entities who can reach and influence potential buyers and appropriate infrastructure players. Cooperative efforts with utilities will be established to facilitate interconnection of electricity producing solar equipment.

These actions will build the bridges and open the doors to allow the commercial offerings, the technical advances in coming years, and available financial incentives to come into play.

<u>FY 1999 Budget Request for Fundamental Solar Photovoltaic Research</u>

Q22. The PCAST report on page 6-17, notes that "The weakest part of the DOE PV program is fundamental materials science research.. . . The long-term outlook for PV would be enhanced if there were broader materials basis for the technology." However, DOE's FY 1999 request for photovoltaic fundamental research is only $11 million, a 0% increase over the current level. Why is that?

A22. With respect to photovoltaics R&D, we are trying to keep a balanced program of fundamental research, applied research and technology development, and pre-commercial demonstration with limited funding. In particular, we must balance our core fundamental research program with more applied research, such as our on-going thin-film R&D which is expected to lead to a new generation of cell technologies for the mid-term. Currently, we are intensively investigating the newer thin-film photovoltaic materials, such as amorphous silicon, cadmium telluride, and copper indium diselenide alloys, which will provide the next generation of high-performance lower cost photovoltaic modules. This work is exemplified by our increasingly successful Thin-Film

Partnership, which has been responsible for achieving several world-record thin-film efficiencies as well as an advanced understanding of fundamental device mechanisms. The attractiveness of these and similar opportunities provides strong motivation to increase applied research investment where possible. Such increases are balanced by support in fundamental research provided by the Office of Energy Research for several material research projects at NREL. When funding for fundamental research and thin-film materials research are considered together, approximately 50% of PV program research funding is used for next generation materials that will replace today's crystal silicon technology.

FY 1999 Budget Request for PV Manufacturing

Q23. The U.S. PV market is booming and a recent *Energy Daily* article raised the possibility of silicon shortages if demand continued to increase. In spite of this, DOE is proposing a 49 percent increase for manufacturing R&D that appears to be a subsidy for an already prosperous business. Why is this an appropriate expenditure of taxpayers' funds?

A23. We believe that no one in the photovoltaic energy supply business would describe the current environment as a PV energy market "boom." While sales of products have increased, penetration into U.S. electricity supply markets has been slow. Because the industry is embryonic, Federal R&D plays a critical role in positioning PV technology to make meaningful contributions to the energy needs of the nation. Despite recent growth, the PV industry is minuscule compared to other energy industries and has low or non-existent profit margins. There continue to be substantial barriers to greater use of PV in bulk electricity production, the most significant of which is high capital cost. Because manufacturing processes are the most significant contributor to PV cost, the PV Materials program address a critical technology weakness. Without Federal R&D support for processing technology, development would slow dramatically and a portion of the private investment likely would also be withdrawn. Furthermore, the PV Materials program provides an efficient mechanism to promote greater industry independence by fostering a more rapid cycle of scaling up production, driving down costs, achieving increased sales, making possible further increases in production volumes and still lower costs.

The PV Materials program (PVMaT) has been very successful at meeting its goals. The average module manufacturing cost from 1992 to 1997 has been reduced by almost 50%. Industry repeatedly assigns highest priority to the PVMaT project, praises its many accomplishments, and provides substantial support through an average 42% cost sharing.

There is no shortage of silicon per se. Comments about silicon shortages refer to single crystal silicon wafers, the traditional mainstay of electronic semiconductor integrated circuits and used in many photovoltaic panels today. Newer types of PV modules, such as thin film designs, do not rely on single crystal wafers.

One of the benefits of PVMaT is that the initiative actually leads to a reduction of single crystal feedstock required to produce a megawatt of product. For example, one industry participant has increased the ratio of finished product to silicon feedstock by over 100% under PVMaT. By utilizing ultra thin wire saw technology developed under their PVMaT contract, the firm has doubled the number of wafers they can produce from a ton of silicon feedstock. Others have also reported similar reductions in feedstock utilization under their PVMaT contracts. More to the point, however, a major portion of the PV R&D effort is directed toward improving the performance of low cost thin film technologies which do not require semiconductor grade silicon as feedstock and use a much smaller amount of raw silicon material than today's crystalline silicon technology.

FY 1999 Budget Request for Biomass

Q24. DOE's budget request includes increases of $20 million to building a facility for burning biomass and $9.3 million for cofiring coal and biomass. Burning biomass is not exactly a new technology. Why is DOE proposing to spend such large sums on this?

A24. Conventional biomass conversion technologies are largely limited to the forest products industry where the fuel is free. In other markets, both the feedstock and conversion costs are currently higher than conventional power generation technologies. DOE's objective is to bring down these costs through cost sharing with industry the development of efficient conversion technology for large scale power production and the establishment of sustainable biomass energy supplies via dedicated energy crops. Successful integration of energy crops for sustainable power production not only cuts the cost of biomass power generation, but can have direct positive impacts on farm income and rural communities, with additional benefits of watershed protection and soil stabilization.

Two of the major pathways to efficient use of biomass resources involve gasification of biomass to fuel advanced combined cycle plants and use of biomass as cofire fuel in modern pulverized coal boilers.

Gasification combined-cycle technology is at the commercial-scale, proof-of-concept stage of development, and is being demonstrated through projects like the Minnesota Valley Alfalfa Producers (MnVAP) project, which is highly cost-shared (75% outside funding/25% DOE funding).

The MnVAP project is one of three industry cost shared projects that comprise the Biomass for Rural Development Project. It will utilize air-blown, fluidized-bed gasification technology to convert alfalfa stems into a hot, clean, low heating value gas. The biomass synthesis gas will be used in a gas turbine in the same manner that natural gas is used. Electricity will be generated using a high efficiency combined cycle (gas turbine and steam turbine) power generation system. Using high efficiency power cycles reduces the cost of producing electricity. This technology has proven effective at bench scales and a number of smaller demonstrations, but it represents a significant technical and financial risk at commercial scales. The other two projects, the Chariton Valley and Salix Consortium projects, will develop the use of switchgrass and willow energy crops respectively, in cofiring applications in large power company boilers. Again, establishing sustainable, low-costs, biomass energy supplies are the keys to the success of these projects.

Cofiring in high efficiency pulverized coal boilers is being evaluated by a few pioneering power companies in cooperation with the Department of Energy. DOE is seeking to support novel approaches to cofiring that will reduce the technical risk of using biomass in large power generation boilers and will enhance the environmental benefits of cofiring. Owners of coal fired generators view cofiring as a means to extend the life of coal fired facilities in the Midwest and Northeast while improving the environmental profile of coal generation.

Firing biomass in large power generation boilers to gain the efficiency advantage of modern pulverized coal boilers represents a significant technical risk. Using biomass in pulverized coal boilers at high co-firing percentages (up to 20%) requires completely separate fuel processing systems. These include handling and sizing the material for introduction into the boiler, and combustion controls may have to be modified to handle variations in fuel parameters. Moreover, there is evidence that biomass feedstock can be used as a "reburn fuel" to reduce NOx emissions. ("Reburning" entails the insertion of a secondary combustion feedstock into the combustion chamber, following a conventional combustion process, and using this additional fuel to more completely burn the hot gasses released in the initial combustion.) The initiative will cost share efforts to reduce the technical risk of biomass co-firing in the large scale boilers with significant system improvements. This effort is becoming increasingly important as the new National Ambient Air Quality Standards (NAAQS) are implemented.

Q25. **DOE proposes a $5.3 million increase to continue designing and constructing ethanol facilities, and subsidizing private companies at the 50% level. How can this be justified as a credible expenditure of R&D funds?**

A25. The Department's requested increase of $5.3 million is to develop additional cost-shared partnerships for design and construction of cellulosic waste-to-ethanol facilities. The Department's role in these partnerships is to provide research, technical, and engineering assistance that will reduce the risks of first-of-a-kind pilot technology demonstrations in industry-owned, privately financed facilities. We also recognize that evidence of DOE interest could be instrumental in helping these partners obtain private financing. The Energy Policy Act of 1992 requires a minimum of 50% cost share for demonstration projects, but the Department anticipates that our partners of these facilities will provide higher cost-share percentages. For example, DOE's current partnership with BC International for a sugarcane bagasse-to-ethanol demonstration facility in Louisiana had a DOE cost share of $2,000,000 and a BC International share of $6,200,000 (76%) in FY 1997; in FY 1998, the DOE share is $4,000,000 and the BC International share is $27,600,000 (87%).

<u>FY 1999 Budget Request for Wind</u>

Q26. **The U.S. wind business is doing well, yet DOE is proposing to hand out $4.0 million to commercial suppliers of grid electricity. Why?**

A26. The U.S. wind industry is not doing well. The industry faces intense competition from foreign companies in nations whose governments offer manufacturers tied aid and other market support not generally available to U.S. firms. This competition takes place both in the U.S. marketplace and abroad. In 1997, only about 20 MW of United States wind technology was installed world-wide out of a total of 1500 MW new installations. Several hundred megawatts of U.S. wind turbines are expected to be installed in 1998-2000, but that is only a small fraction of the expected total world market. Improved technology is needed for the U.S. wind industry to be competitive. DOE's Wind Energy programs are designed to help industry achieve this goal.

The Department is not proposing to "hand out" $4.0 million to a commercial supplier of electricity. The requested funds would support testing at the National Wind Technology Center by laboratory and industry researchers, resource assessment for mini-grid projects in developing countries, control system testing and performance monitoring for wind/hybrid projects in the United States, and certain off-grid wind activities of the Departments of Agriculture and Defense.

This activity is key to positioning wind as an important, cost-competitive U.S. clean energy option. It is part of an overall effort to help the U.S. industry leapfrog its foreign competition in the post-2000 time frame via the next-generation turbines currently under development. The program strives to expand the capacity of domestic wind sites so that wind sites in the Midwest may become productive.

FY 1999 Budget Request for Solar Market Promotion Activities

Q27. DOE is proposing increases of $14 million for "Solar Program Support," $8.8 million for International Solar Energy," and $1.4 million for "Solar Technology Transfer." These appear to be solely market promotion activities that have nothing to do with R&D. How can these increases be justified?

A27. Of the $14 million for "Solar Program Support," $4 million is for electricity restructuring research and outreach efforts to the states. The nature of these research and outreach activities is to provide state and Federal decision makers with information on the workings and potential impacts of policy and market-based mechanisms such as renewable portfolio standards, systems benefits charges, and information disclosure provisions. These mechanisms have been only sparingly used and Federal, state, and local policy officials need information about their costs and effectiveness. Research is needed to ensure that these mechanisms are designed and implemented properly and that they produce the desired results. The Federal government can play an important national clearinghouse function in fostering the exchange of information and lessons learned and in ensuring that the maximum amount of leveraging of financial and technical resources is taking place among the states and between the states and the Federal government.

Specific activities that would be undertaken include: 1) continuation of regional restructuring networks to provide information to state policy officials and encourage regional interactions; 2) operation of a website (and expansion of Internet delivery techniques) to disseminate relevant research results and other items of interest to state and Federal policy officials; 3) provision of technical assistance to the states in their implementation of systems benefits charges, information disclosure provisions, and renewable portfolio standards to leverage resources and maximize impacts; 4) analysis of retail choice policies and determination of the effectiveness of green marketing, information disclosure, and provision of energy services as mechanisms in delivering energy and environmental benefits to consumers; and 5) assessment of the national impacts of electricity restructuring on the development and deployment of renewable and energy efficiency technologies and the conduct of collaborative energy R&D programs.

Also under Solar Program Support, $10 million is requested for a new, technology-neutral Competitive Solicitation. This solicitation would seek the best ideas on how to effectively deploy renewable technologies, whether singularly, in combination with other renewable technologies, or in hybrid configurations with natural gas or energy storage systems. The intent of this effort is to build on the public's growing interest in clean energy sources that protect the environment and provide an expanded experience base for further use of renewables in a restructured power sector. While renewable technologies can, in selected instances, be cost-competitive today on a life-cycle basis, the emerging restructured utility environment often favors low first-cost options. Increased in-service data is needed to support technology development programs and remote and off-grid applications represent important targets of opportunity. For example, we expect applications in farming areas, where wind, solar and biomass resources often coexist. We also anticipate that there would be substantial applications on Native American tribal lands, where half the population still lacks access to electricity. Of the $10 million proposed for the initiative in FY 1999, up to $3 million will be dedicated to projects benefiting Native Americans.

The $8.8 million requested for International Solar Energy would increase funding for Joint Implementation activities and restore funding to two important export-promotion programs, Committee on Renewable Energy Commerce and Trade (CORECT) and the Americas 21st Century Program (A21). A21, a U.S. government/industry collaboration, has been instrumental in identifying cost effective applications, for solar energy projects, opening world markets for U.S. companies, and securing project financing. CORECT and A21 have been key to the development of a substantial market for U.S. firms in more than 50 countries throughout Latin America and the Caribbean, Asia and Africa. These programs have assisted U.S. industry through collaboration on: energy policy and regulatory reform to level the playing field so that new and emerging technologies have equal opportunity with traditional energy technologies; development of project opportunities in energy and related sectors (e.g., agriculture, telecommunications, education tourism); creating models for sustainable development and delivery of renewable energy and energy efficiency services; development of product/service distribution infrastructures; and provision of private sector solutions to global climate change challenges.

The World Bank has estimated that developing countries alone over the next four decades will require 5 million megawatts of new electrical capacity to meet the needs of their citizens and their expanding economies. To put this number into perspective, the world's total installed capacity today is just under 3 million megawatts. Our global competitors, with significant governmental support, are working aggressively to secure a greater share of that market as they seek to triple their production capacity over the next three years. The U.S. solar industry must meet this challenge if it is to remain competitive internationally and DOE's Solar International Programs play a vital role in that effort. By assisting U.S. firms to enter these world markets and deploy their technologies, DOE's Solar International Programs help to build an economically and environmentally sound future both here at home and in countries around the world while simultaneously providing much needed operating data for feedback to technology development efforts..

The "Solar Technology Transfer program" is an information sharing effort that supports the Energy Efficiency and Renewable Clearinghouse (EREC). EREC responds to public inquiries about energy efficiency and renewable energy technologies. This is part of the overall effort to ensure that the public is well informed on the status of these technologies. EREC makes the results of DOE RD&D accessible to homeowners, business owners, building managers, engineers, the financial community, students, and others. EREC responded to over 110,000 requests for information during FY97 and continues to have a high level of user satisfaction.. The $1.4 million for Solar Technology Transfer allows us to meet growing public demand for clear, reliable technical information on energy efficiency and renewable energy technologies.

FY 1999 Budget Request for Nuclear

Q28. Please describe the new $24 million Nuclear Energy Research Initiative. Why is it needed?

A28. The Energy Research and Development Panel of the President's Committee of Advisors on Science and Technology (PCAST), in its November 1997 report, determined that the establishment of nuclear energy as a viable and expandable energy option was important and that a properly focused R&D effort was needed to address the long-term barriers to the expanded use of nuclear energy.

These barriers include proliferation of nuclear material, reactor safety, nuclear waste, and economics of nuclear plants. The PCAST panel further recommended that the Department reinvigorate its nuclear energy research and development activities to address these barriers with a new research approach based on competitive selection of research proposals from universities, national laboratories and industry.

In response, the Department proposed the Nuclear Energy Research Initiative (NERI) to address the key issues affecting nuclear energy and to preserve the nation's nuclear science and technology capabilities and leadership. To achieve this long-range goal, the Department established the following objectives for the program:

1. Support the development of advanced concepts and scientific breakthroughs in nuclear fission and reactor technology that will further enhance nuclear energy as a safe, environmentally sound, and cost effective global energy source;
2. Focus the university, national laboratory and industry R&D infrastructure on nuclear energy issues and foster collaborative basic and mission-oriented research and development;
3. Facilitate technology transfer from other research areas to the nuclear energy and science challenges of the private sector; and
4. Encourage international cooperation in addressing nuclear technology issues.

NERI will support research in key areas such as: proliferation resistant reactors and fuel cycles; new reactor designs with higher efficiencies, lower cost and improved safety; lower output reactors for use where large reactors are not attractive; and new nuclear waste technologies.

NERI will feature a competitive, peer-review R&D selection process to fund researcher-initiated R&D proposals. This process will be similar to that used by the Department's Environmental Management Science Program. The Department's Office of Energy Research, is advising the Office of Nuclear Energy in developing this program.

Q29. Why have you proposed the $10 million Nuclear Energy Plant Optimization program in your FY99 budget? Why is directly subsidizing existing nuclear plants an appropriate Federal program, and in the best interest of the country?

A29. Nuclear power provides 20 percent of U.S. electricity without producing carbon dioxide or other air pollution. Since utilities are choosing to shutdown some of these nuclear power plants prematurely while the national interest may be served by keeping them operating, the President's Council of Advisors on Science and Technology (PCAST) recommended that DOE work with its laboratories and the utility industry to develop the specifics of a research and development program to address the problems that may prevent continued operation of the current plants and to fund such a program at $10 million per year, to be matched by industry. In response to this recommendation, DOE proposed the Nuclear Energy Plant Optimization (NEPO) initiative in the FY 1999 budget.

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FY 1999 Budget Request for the Climate Change Technology Initiative

Q30. Please provide a detailed breakdown (by appropriation account, program, project, activity) of DOE's FY 1999 budget request for the Climate Change Technology Initiative. Please also provide the actual FY 1997 and estimated FY 1998 funding for the items included in this initiative.

A30. As requested, the attached funding table provides a detailed breakdwon for the Climate Change Technology Initiative.

DEPARTMENT OF ENERGY
Climate Change Technology Initiative
FY 1999 CONGRESSIONAL BUDGET REQUEST
ENERGY CONSERVATION APPROPRIATION
(Dollars in thousands)

Energy Efficiency
PROGRAM FUNDING DETAIL

Program/Subprogram/Activity	FY 1997 Enacted	FY 1998 Enacted	FY 1999 Request
I. Transportation Sector, Total	172,457	193,271	246,096
A. Technology Deployment	10,618	11,775	16,250
B. Advanced Automotive Technologies	102,717	113,296	144,646
C. Advanced Heavy Vehicle Technologies	19,129	25,600	44,200
D. Transportation Materials Technologies	32,256	35,000	31,800
E. Implementation and Program Management	7,737	7,600	9,200
II. Building Technology, State, and Community Sector, Total	80,054	78,780	126,445
A. Building Systems Design	23,255	22,986	36,373
B. Building Equipment and Materials	26,080	26,921	46,181
C. Codes & Standards	11,810	14,423	22,573
D. State and Local Partnership Programs	1,576	1,600	6,600
E. Management and Planning	17,333	12,850	14,718
III. Federal Energy Management Program, Total	19,800	19,800	33,868
IV. Industry Sector, Total	115,424	136,197	166,559

DEPARTMENT OF ENERGY
Climate Change Technology Initiative
FY 1999 CONGRESSIONAL BUDGET REQUEST
ENERGY CONSERVATION APPROPRIATION
(Dollars in thousands)

Energy Efficiency
PROGRAM FUNDING DETAIL

Program/Subprogram/Activity	FY 1997 Enacted	FY 1998 Enacted	FY 1999 Request
A. Industries of the Future (Specific)	45,332	53,078	76,000
B. Industries of the Future (Crosscutting)	38,378	49,120	49,400
C. Technology Access	24,827	26,299	32,000
D. Management & Planning	6,887	7,700	9,159
V. Policy and Management - EC, Total	26,403	28,580	44,432
R&D	414,138	456,628	617,400
SUBTOTAL ENERGY CONSERVATION APPR.	414,138	456,628	617,400
Financing: Use of Prior Year	(480)	0	0
Subtotal	413,658	456,628	617,400
TOTAL ENERGY CONSERVATION APPR.	413,658	456,628	617,400
Total FTEs	432	430	427

DEPARTMENT OF ENERGY
FY 1999 CONGRESSIONAL BUDGET REQUEST
Climate Change Technology Initiative
ENERGY SUPPLY APPROPRIATION
(Dollars in thousands)

SOLAR AND RENEWABLE ENERGY
PROGRAM FUNDING DETAIL

Program/Subprogram/Activity	FY 1997 Current Appropriation	FY 1998 Current Appropriation	FY 1999 Request
I. Solar and Renewable Energy	$266,187	$296,666	$389,251
A. Solar Building Technology Research	2,277	2,658	5,000
1. Space Conditioning and Water Heating	2,277	2,658	5,000
B. Photovoltaic Energy Systems	59,210	65,498	78,800
1. Fundamental Research	9,921	11,000	11,000
2. Advanced Materials and Devices	23,289	24,000	27,000
3. Collector Research & Systems Development	26,000	30,498	40,800
C. Solar Thermal Energy Systems	21,924	16,519	22,500
1. Solar Thermal Electric R&D	21,924	16,519	22,500
a. Thermal Systems Research	8,387	6,150	5,500
b. Power Applications Research	13,537	10,369	17,000
D. Biopower/Biofuels Energy Systems	54,327	58,840	89,791
1. Biopower Energy Systems- Utilities	27,162	28,164	42,900
a. Thermochemical Conversion	1,272	1,500	2,700

DEPARTMENT OF ENERGY
FY 1999 CONGRESSIONAL BUDGET REQUEST
Climate Change Technology Initiative
ENERGY SUPPLY APPROPRIATION
(Dollars in thousands)

SOLAR AND RENEWABLE ENERGY
PROGRAM FUNDING DETAIL

Program/Subprogram/Activity	FY 1997 Current Appropriation	FY 1998 Current Appropriation	FY 1999 Request
b. System Development	18,262	21,392	37,300
c. Biomass for Cogeneration	3,953	2,564	2,900
d. Feedstock Production	2,100	1,723	0
e. Regional Biomass Energy Program	1,575	985	0
2. Biofuels Energy Systems - Transportation	$27,165	$30,676	$46,891
a. Ethanol Production	22,165	25,426	36,391
b. Biodiesel Production	750	750	1,000
c. Feedstock Development	2,500	2,500	6,000
d. Regional Biomass Energy Program	1,750	2,000	3,500
E. Wind Energy Systems	28,646	32,527	43,500
1. Applied Research	12,200	11,500	10,700
2. Turbine Research	8,500	13,000	24,800
3. Cooperative Research & Testing	7,946	8,027	8,000
F. Renewable Energy Production Incentive Program	2,000	2,954	4,000

DEPARTMENT OF ENERGY
FY 1999 CONGRESSIONAL BUDGET REQUEST
Climate Change Technology Initiative
ENERGY SUPPLY APPROPRIATION
(Dollars in thousands)

**SOLAR AND RENEWABLE ENERGY
PROGRAM FUNDING DETAIL**

Program/Subprogram/Activity	FY 1997 Current Appropriation	FY 1998 Current Appropriation	FY 1999 Request
G. Solar Program Support	0	0	14,000
1. Electric Restructuring	0	0	4,000
2. 5-Year Open Competitive Solicitation	0	0	10,000
H. International Solar Energy Program	661	1,375	8,800
I. Solar Technology Transfer	$0	$0	$1,360
1. Information & Communications	0	0	1,360
J. National Renewable Energy Laboratory	3,300	3,200	5,000
1. Facility Maintenance	500	1,000	5,000
2. Construction	2,800	2,200	0
K. Geothermal	29,630	29,051	33,000
1. Geothermal Electric R&D and Deployment	23,148	22,651	29,500
2. Geothermal Heat Pump Deployment	6,482	6,400	3,500
L. Hydrogen Research and Development	14,809	16,003	24,000

DEPARTMENT OF ENERGY
FY 1999 CONGRESSIONAL BUDGET REQUEST
Climate Change Technology Initiative
ENERGY SUPPLY APPROPRIATION
(Dollars in thousands)

SOLAR AND RENEWABLE ENERGY
PROGRAM FUNDING DETAIL

Program/Subprogram/Activity	FY 1997 Current Appropriation	FY 1998 Current Appropriation	FY 1999 Request
M Hydropower Development	973	739	4,000
N. Renewable Indian Energy Resources Program	4,000	3,939	0
O. Electric Energy Systems and Storage	31,378	42,788	38,500
1. High Temperature Superconductivity R&D	19,518	32,005	32,000
2. Energy Storage R&D	3,954	3,890	6,000
3. Electric & Magnetic Fields R&D	7,906	6,893	0
4. Climate Challenge	0	0	500
P. Program Direction	$13,052	$15,651	$17,000
1. Golden Field Office	2,230	1,890	2,526
a. Salary and Benefits	1,326	980	915
b. Travel	72	75	80
c. Support Services	447	464	852
d. Other Related Expenses	385	371	679
2. Idaho Operations Office	99	179	186

DEPARTMENT OF ENERGY
FY 1999 CONGRESSIONAL BUDGET REQUEST
Climate Change Technology Initiative
ENERGY SUPPLY APPROPRIATION
(Dollars in thousands)

SOLAR AND RENEWABLE ENERGY
PROGRAM FUNDING DETAIL

Program/Subprogram/Activity	FY 1997 Current Appropriation	FY 1998 Current Appropriation	FY 1999 Request
a. Salary and Benefits	85	176	181
b. Travel	14	3	5
c. Support Services	0	0	0
d. Other Related Expenses	0	0	0
3. Headquarters.	10,723	13,582	14,288
a. Salary and Benefits	8,864	8,750	8,320
b. Travel	267	320	335
c. Support Services	0	2,862	3,943
d. Other Related Expenses	1,592	1,650	1,690
Total Program Direction Summary	13,052	15,651	17,000
a. Salary and Benefits	10,275	9,906	9,416
b. Travel	353	398	420
c. Support Services	447	3,326	4,795
d. Other Related Expenses	1,977	2,021	2,369
Q. Federal Building/Remote Power Initiative	$0	$4,924	$0
R&D	266,187	296,666	389,251

DEPARTMENT OF ENERGY
FY 1999 CONGRESSIONAL BUDGET REQUEST
Climate Change Technology Initiative
ENERGY SUPPLY APPROPRIATION
(Dollars in thousands)

SOLAR AND RENEWABLE ENERGY
PROGRAM FUNDING DETAIL

Program/Subprogram/Activity	FY 1997 Current Appropriation	FY 1998 Current Appropriation	FY 1999 Request
SUBTOTAL Energy Supply	266,187	296,666	389,251
Use of Prior Year Balances Solar & Renewable	(22,367)	(24,447)	(17,000)
TOTAL Energy Supply	$243,820	$272,219	$372,251
Staffing (FTEs):			
Golden Field Office	24	17	15
Idaho Operations Office	1	2	2
Headquarters	98	92	85
Total FTEs	123	111	102

Post-Hearing Questions Submitted by the Honorable Mike Doyle (PA-18)

Carbon Sequestration

Q1. What is the total budget request for carbon sequestration research and development activities at DOE for FY 1999? How does this compare to the funding DOE received for carbon sequestration activities in FY 1997 and FY 1998?

The Department has requested $39 million in FY 1999 for carbon sequestration and cross-cutting research:

— The Energy Research program is requesting $27 million in FY 1999 for carbon management research focused in three areas: science for efficient technologies; fundamental science underpinning advances in all low/no carbon energy sources; and sequestration science. $9 million has been specifically identified for carbon sequestration research and development activities in three program areas; $4 million for biological capture research and $2 million for ocean sequestration research in the Biological and Environmental Research program (BER); and $3 million for underground sequestration research in the Basic Energy Sciences (BES) program. There was no funding in the Energy Research Program budget in either FY 1997 or FY 1998 specifically identified for carbon sequestration, however the carbon sequestration research proposed in the FY 1999 budget builds upon specific precursor Basic research that was funded in both the FY 1997 and FY 1998 budget.

— The Fossil Energy program is requesting $12 million in FY 1999 for carbon sequestration technologies research. The Fossil Energy program received $1.0 million in FY 1997 and $1.5 million in FY 1998 for carbon sequestration research activities.

Q2. Please provide a list of:

Q2.1 All projects that DOE is pursuing that are characterized as carbon sequestration activities with a comparison of the FY 1998 and proposed FY 1999 funding level for each project.

Project	$ in thousands FY 1998	FY 1999
1. Research to investigate the biological capture of atmospheric CO_2 by plants and to determine how quantities might be augmented. (BER)	0	4,000
2. Research to investigate the biological capture of ocean CO_2 sequestration and how these processes might be augmented. (BER)	0	2,000
3. Research in geophysics and geomechanics to assist in evaluating the potential for CO_2 sequestration in subsurface geological formations	0	3,000

The carbon sequestration projects ongoing and planned for Fossil Energy are:

Project	$ in thousands FY 1998	FY 1999
1. Collaborative research and development of advanced technologies for greenhouse gas separation, capture, storage and reuse, including field testing. Type I Sequestration	279	1,890
2. Collaborative research and technology development to integrate fossil fuel production and use with natural sinks enhancement (includes activities with International Energy Agency Greenhouse Gas R&D Program, Electric Power Research Institute, and other industry groups). Type II Sequestration	400	2,500

3.	Novel "path breaking" concepts for reducing greenhouse gas emissions (FY 1998 solicitations) and exploratory and collaborative research on advanced concepts. Type III Sequestration	900	7,500

Q2.2 A description of which of these projects pertain to coal utilization including a description of the nature of this relationship, if any, for each project.

Project	Relation to Coal
1	Collaborative research with industry and IEA/GHG emphasizes advanced technology for separation, capture, and reuse of CO_2 from all coal-fired technologies, and on evaluating potential storage options that are applicable for storage of CO_2 from all coal-fired technologies.
2	The collaborative research and collaborations with the electric utility industry, and the IEA Greenhouse Gas R&D Programme (IEA/GHG), and other industry groups emphasizes measures to reduce or offset emissions from both existing and new coal-fired plants.
3	The competitive solicitation awards to be made in FY 1998, and subsequent years, and the other activities emphasize revolutionary approaches for reductions from coal using facilities and technologies.

<u>Clean Coal Technology Demonstration Program</u>

Q3. Page 129 of the FY 1999 DOE Budget Highlights, which describes expenditures for the Clean Coal Technology Demonstration Program (CCTD), cites "reducing CO_2 emissions" as a goal of this program.

Q3.1 Has this always been the case, or is this a new mission of the CCTD program?

A3.1. This is not a new mission of the CCTD program. All five solicitations (Program Opportunity Notices [PON]) issued for the CCTD program have requested proposals that included the requirement to demonstrate novel technologies that utilize coal in an environmentally responsible manner. The need to reduce emissions of greenhouse gases, including CO_2 emissions, was specifically included in technical evaluation criteria specified in the third solicitation (PON NUMBER DE-PS01-89FE61825) issued May 1, 1989, and in the fourth solicitation (PON NUMBER DE-PS01-91FE62271) issued January 17, 1991. These technical evaluation criteria were considered by the Department in the comprehensive evaluation of proposals leading to selections.

Q3.2 If it is a new mission, please explain how the addition of this new goal impacts the funding of CCTD projects to reduce SO_2 and NO_X?

A3.2 Reducing emissions of CO_2 is not a new mission for the CCTD program.

Q3.3 If the goal of reducing carbon emissions from coal combustion is not a new goal, please cite past references to the carbon reduction goal.

A3.3 Refer to A3.1 for past references.

<u>The Kyoto Accord and Electricity Deregulation</u>

Q4. Given the emissions-reduction constraints that will result from the Kyoto accord, what will do you anticipate will happen to power-generating utilities in a deregulated marketplace?

A4. We believe that the introduction of competition into the electric utility sector will reduce greenhouse gas emissions relative to a baseline projection. The Department's analyses have identified both emissions-increasing and emissions-reducing forces associated with the advent of competition. Examples of the latter include profit incentives for cost-effective efficiency improvements that lower fuel consumption per unit of generation at existing plants, increased market opportunities for efficient new merchant power plants with far better emissions characteristics than the old plants they can displace, and opportunities for competitive sellers to attract and retain customers by offering "green power" or energy efficiency services bundled with electricity to better meet customer needs. Clear information disclosure and labeling policies will help consumers to make electricity decisions that reflect their environmental concerns. These beneficial effects of competition identified above are expected to outweigh its commonly-identified emissions-increasing effects (due, for example, to lower prices). Policies explicitly designed to promote renewable energy or to fund public benefits programs, such as those included in the Administration's Comprehensive Electricity Competition Plan, can provide further significant reductions in emissions.

Q4.1 Do you anticipate that the current generation of coal-fired power plants will remain open?

A4.1 The projected future operation of the current generation of coal-fired power plants does not depend significantly on the rate at which competition is introduced into electric power markets. These plants are expected to provide more than half of the nation's electric power through the year 2010 under either a cost-of-service or a full retail competition scenario.

Ratification and implementation of the Kyoto Protocol could potentially have more significant implications for the use of these plants beyond 2008. In a ratification scenario, the outcome would depend heavily on the emphasis placed domestic emissions reduction relative to alternative compliance strategies such as international emissions trading among countries with targets or the generation of emissions credits through the Clean Development Mechanism. It would also depend on the strategy selected to deliver the domestic component of emissions reduction. Most existing plants would be very competitive if the implicit value of carbon in a Kyoto compliance scenario fell within the range presented in recent testimony by Chair Yellen of the Council of Economic Advisers.

Q4.2 If not, what do you anticipate will make up for this decrease in generating capacity?

A4.2 As noted above, we do not expect competition to trigger the "if not" scenario. Under the Administration's projections regarding the value of carbon in a compliance scenario, neither would the Kyoto Protocol.

Ratio of Funding Between DOE's Climate Change-Related R&D Efforts Reared Towards Energy Production and Energy End-Use

Q5. Of DOE's climate change-related R&D efforts, what is the ratio of funding between efforts geared towards energy production and energy end-use?

A5. Attached is a breakdown of DOE activities under the Climate Change Technology Initiative, as described in the Administration's FY99 budget request. While the listed DOE activities certainly aim to mitigate greenhouse gas emissions, they also aim to fulfill other economic, environmental and energy security goals and generally would be pursued even in the absence of a climate change policy initiative. Funding of energy production efforts would roughly encompass the solar and renewable activities under the Office of Energy Efficiency and Renewable Energy (EE) as well as the activities of the activities of the Offices of Nuclear Energy and Fossil Energy. Funding of energy demand efforts would roughly encompass the activities of energy conservation under EE. The Office of Energy Research engages in scientific research and the Energy Information Administration provides data and economic Analysis; these activities advance the efforts of both energy production and energy end-use.

DEPARTMENT OF ENERGY
Climate Change Technology Initiative
FY 1999 CONGRESSIONAL BUDGET REQUEST
ENERGY CONSERVATION APPROPRIATION
(Dollars in thousands)

Energy Efficiency
PROGRAM FUNDING DETAIL

Program/Subprogram/Activity	FY 1997 Enacted	FY 1998 Enacted	FY 1999 Request
I. Transportation Sector, Total	172,457	193,271	246,096
A. Technology Deployment	10,618	11,775	16,250
B. Advanced Automotive Technologies	102,717	113,296	144,646
C. Advanced Heavy Vehicle Technologies	19,129	25,600	44,200
D. Transportation Materials Technologies	32,256	35,000	31,800
E. Implementation and Program Management	7,737	7,600	9,200
II. Building Technology, State, and Community Sector, Total	80,054	78,780	126,445
A. Building Systems Design	23,255	22,986	36,373
B. Building Equipment and Materials	26,080	26,921	46,181
C. Codes & Standards	11,810	14,423	22,573
D. State and Local Partnership Programs	1,576	1,600	6,600
E. Management and Planning	17,333	12,850	14,718
III. Federal Energy Management Program, Total	19,800	19,800	33,868
IV. Industry Sector, Total	115,424	136,197	166,559

DEPARTMENT OF ENERGY
Climate Change Technology Initiative
FY 1999 CONGRESSIONAL BUDGET REQUEST
ENERGY CONSERVATION APPROPRIATION
(Dollars in thousands)

Energy Efficiency
PROGRAM FUNDING DETAIL

Program/Subprogram/Activity	FY 1997 Enacted	FY 1998 Enacted	FY 1999 Request
A. Industries of the Future (Specific)	45,332	53,078	76,000
B. Industries of the Future (Crosscutting)	38,378	49,120	49,400
C. Technology Access	24,827	26,299	32,000
D. Management & Planning	6,887	7,700	9,159
V. Policy and Management - EC, Total	26,403	28,580	44,432
R&D	414,138	456,628	617,400
SUBTOTAL ENERGY CONSERVATION APPR.	414,138	456,628	617,400
Financing: Use of Prior Year	(480)	0	0
Subtotal	413,658	456,628	617,400
TOTAL ENERGY CONSERVATION APPR.	413,658	456,628	617,400
Total FTEs	432	430	427

DEPARTMENT OF ENERGY
FY 1999 CONGRESSIONAL BUDGET REQUEST
Climate Change Technology Initiative
ENERGY SUPPLY APPROPRIATION
(Dollars in thousands)

SOLAR AND RENEWABLE ENERGY
PROGRAM FUNDING DETAIL

Program/Subprogram/Activity	FY 1997 Current Appropriation	FY 1998 Current Appropriation	FY 1999 Request
I. Solar and Renewable Energy	$266,187	$296,666	$389,251
A. Solar Building Technology Research	2,277	2,658	5,000
1. Space Conditioning and Water Heating	2,277	2,658	5,000
B. Photovoltaic Energy Systems	59,210	65,498	78,800
1. Fundamental Research	9,921	11,000	11,000
2. Advanced Materials and Devices	23,289	24,000	27,000
3. Collector Research & Systems Development	26,000	30,498	40,800
C. Solar Thermal Energy Systems	21,924	16,519	22,500
1. Solar Thermal Electric R&D	21,924	16,519	22,500
a. Thermal Systems Research	8,387	6,150	5,500
b. Power Applications Research	13,537	10,369	17,000
D. Biopower/Biofuels Energy Systems	54,327	58,840	89,791
1. Biopower Energy Systems- Utilities	27,162	28,164	42,900
a. Thermochemical Conversion	1,272	1,500	2,700

DEPARTMENT OF ENERGY
FY 1999 CONGRESSIONAL BUDGET REQUEST
Climate Change Technology Initiative
ENERGY SUPPLY APPROPRIATION
(Dollars in thousands)

SOLAR AND RENEWABLE ENERGY
PROGRAM FUNDING DETAIL

Program/Subprogram/Activity	FY 1997 Current Appropriation	FY 1998 Current Appropriation	FY 1999 Request.
b. System Development	18,262	21,392	37,300
c. Biomass for Cogeneration	3,953	2,564	2,900
d. Feedstock Production	2,100	1,723	0
e. Regional Biomass Energy Program	1,575	985	0
2. Biofuels Energy Systems - Transportation	$27,165	$30,676	$46,891
a. Ethanol Production	22,165	25,426	36,391
b. Biodiesel Production	750	750	1,000
c. Feedstock Development	2,500	2,500	6,000
d. Regional Biomass Energy Program	1,750	2,000	3,500
E. Wind Energy Systems	28,646	32,527	43,500
1. Applied Research	12,200	11,500	10,700
2. Turbine Research	8,500	13,000	24,800
3. Cooperative Research & Testing	7,946	8,027	8,000
F. Renewable Energy Production Incentive	2,000	2,954	4,000
Program			

DEPARTMENT OF ENERGY
FY 1999 CONGRESSIONAL BUDGET REQUEST
Climate Change Technology Initiative
ENERGY SUPPLY APPROPRIATION
(Dollars in thousands)

SOLAR AND RENEWABLE ENERGY
PROGRAM FUNDING DETAIL

Program/Subprogram/Activity	FY 1997 Current Appropriation	FY 1998 Current Appropriation	FY 1999 Request
G. Solar Program Support	0	0	14,000
1. Electric Restructuring	0	0	4,000
2. 5-Year Open Competitive Solicitation	0	0	10,000
H. International Solar Energy Program	661	1,375	8,800
I. Solar Technology Transfer	$0	$0	$1,360
1. Information & Communications	0	0	1,360
J. National Renewable Energy Laboratory	3,300	3,200	5,000
1. Facility Maintenance	500	1,000	5,000
2. Construction	2,800	2,200	0
K. Geothermal	29,630	29,051	33,000
1. Geothermal Electric R&D and Deployment	23,148	22,651	29,500
2. Geothermal Heat Pump Deployment	6,482	6,400	3,500
L. Hydrogen Research and Development	14,809	16,003	24,000

DEPARTMENT OF ENERGY
FY 1999 CONGRESSIONAL BUDGET REQUEST
Climate Change Technology Initiative
ENERGY SUPPLY APPROPRIATION
(Dollars in thousands)

SOLAR AND RENEWABLE ENERGY
PROGRAM FUNDING DETAIL

Program/Subprogram/Activity	FY 1997 Current Appropriation	FY 1998 Current Appropriation	FY 1999 Request
M Hydropower Development	973	739	4,000
N. Renewable Indian Energy Resources Program	4,000	3,939	0
O. Electric Energy Systems and Storage	31,378	42,788	38,500
1. High Temperature Superconductivity R&D	19,518	32,005	32,000
2. Energy Storage R&D	3,954	3,890	6,000
3. Electric & Magnetic Fields R&D	7,906	6,893	0
4. Climate Challenge	0	0	500
P. Program Direction	$13,052	$15,651	$17,000
1. Golden Field Office	2,230	1,890	2,526
a. Salary and Benefits	1,326	980	915
b. Travel	72	75	80
c. Support Services	447	464	852
d. Other Related Expenses	385	371	679
2. Idaho Operations Office	99	179	186

DEPARTMENT OF ENERGY
FY 1999 CONGRESSIONAL BUDGET REQUEST
Climate Change Technology Initiative
ENERGY SUPPLY APPROPRIATION
(Dollars in thousands)

SOLAR AND RENEWABLE ENERGY
PROGRAM FUNDING DETAIL

Program/Subprogram/Activity	FY 1997 Current Appropriation	FY 1998 Current Appropriation	FY 1999 Request
a. Salary and Benefits	85	176	181
b. Travel	14	3	5
c. Support Services	0	0	0
d. Other Related Expenses	0	0	0
3. Headquarters.	10,723	13,582	14,288
a. Salary and Benefits	8,864	8,750	8,320
b. Travel	267	320	335
c. Support Services	0	2,862	3,943
d. Other Related Expenses	1,592	1,650	1,690
Total Program Direction Summary	13,052	15,651	17,000
a. Salary and Benefits	10,275	9,906	9,416
b. Travel	353	398	420
c. Support Services	447	3,326	4,795
d. Other Related Expenses	1,977	2,021	2,369
Q. Federal Building/Remote Power Initiative	$0	$4,924	$0
R&D	266,187	296,666	389,251

DEPARTMENT OF ENERGY
FY 1999 CONGRESSIONAL BUDGET REQUEST
Climate Change Technology Initiative
ENERGY SUPPLY APPROPRIATION
(Dollars in thousands)

SOLAR AND RENEWABLE ENERGY
PROGRAM FUNDING DETAIL

Program/Subprogram/Activity	FY 1997 Current Appropriation	FY 1998 Current Appropriation	FY 1999 Request
SUBTOTAL Energy Supply	266,187	296,666	389,251
Use of Prior Year Balances Solar & Renewable	(22,367)	(24,447)	(17,000)
TOTAL Energy Supply	$243,820	$272,219	$372,251
Staffing (FTEs):			
Golden Field Office	24	17	15
Idaho Operations Office	1	2	2
Headquarters	98	92	85
Total FTEs	123	111	102

Nuclear Power

Q6. Demand for electricity is predicted to rise steadily into the next century. Given the current contribution of nuclear energy to our energy supply and that technology's lack of greenhouse gas emissions, shouldn't the Administration pay more attention to what nuclear generation can do with respect to Clean Air Act and other emissions reduction requirements?

A6. Yes, and it is doing so. The Energy Research and Development Panel of the President's Committee of Advisors on Science and Technology (PCAST), in its November 1997 report, "Federal Energy Research and Development for the Challenges of the Twenty-First Century," stated that the Federal government's role is to "ensure that long-term problems with nuclear power are addressed so that nuclear can become, if possible, a realistic and acceptable energy option, as well as a hedge in case renewables and efficiency cannot reach the performance levels and market share necessary to meet emission reduction targets." The Department's Strategic Plan, issued by Secretary Peña in September 1997, discusses energy resources as one of our four main business lines. Our Energy Resources strategic goal is to "promote secure, competitive, and environmentally responsible energy systems that serve the needs of the public." To ensure the availability of adequate and affordable electricity supplies with reduced environmental impact, the Department has developed several strategies, including one to "maintain a viable nuclear option for future, carbon-free baseload electricity through cooperative technical development activities with the U.S. electric industry that would facilitate a U.S. order of an advanced nuclear power plant by 2010."

The Department has proposed two new initiatives in its budget request for FY 1999. The proposed Nuclear Plant Optimization Program (NEPO) would partner with industry to develop technologies to address problems that may prevent the continued operation of current nuclear power plants. To this end the Department and industry, through the Electric Power Research Institute (EPRI), together have developed a "Joint DOE-EPRI Strategic Nuclear Energy Research and Development Plan to Optimize U.S. Nuclear Power Plants" to guide the program. The purpose of this strategic plan is to jointly develop and prioritize the essential R&D needs of the commercial nuclear energy industry for the next five to ten years, and to ensure that there is no duplication of effort.

The second program is the proposed Nuclear Energy Research Initiative (NERI) which will sponsor peer-reviewed, competitive R&D to find solutions to those concerns that affect the long term future and expanded use of nuclear energy. Specifically, NERI will develop innovative technologies and reactor concepts to address proliferation, reactor safety, waste and economic concerns.

Q7. What is the Department of Energy's explanation for the fact that several other nations are aggressively pursuing construction of civilian nuclear power plants while no such effort is underway here in the U.S.?

A7. There are several reasons that explain the aggressive pursuit of commercial nuclear energy in some countries as compared to the U.S. First and foremost is the demand for electricity. Electricity demand is growing fast in countries with expanding or developing economies, such as South Korea, China and India. Nations with rapidly increasing electricity demand are attracted to nuclear energy by the security and independence from oil imports, the lack of greenhouse gas emissions associated with fossil fuels, and the ability of nuclear energy to provide large amounts of reliable baseload power. By comparison, U.S. electricity demand is relatively flat. Growth in demand has declined from an annual rate of 7+ percent in the 1950s and 1960s to an average annual rate of 1.5 to 2 percent over the last 20 years. This relatively small increase in U.S. electricity demand during this 20 year period has not required significant new additions to baseload generation capacity. The new demand has been met through completion of nuclear and fossil plants ordered in the 1960s and 1970s, utilization of excess capacity, electricity imports, and existing plant efficiency improvements.

The second reason relates to the availability of natural resources. Countries such as France, Japan, South Korea, India do not have large indigenous supplies, or cheap sources, of coal, natural gas or oil to produce electricity. China has large quantities of coal but lacks the infrastructure to economically mine and transport the coal to the population centers where the power plants are located. The U.S., on the other hand, has vast supplies of cheap coal which currently provide over 50 percent of our nation's electricity generation. In addition, U.S. natural gas supplies have proven much larger than previously realized, resulting in higher production and competitive prices. As a result, gas-fired combined cycle power plants have become the most cost effective new electricity generation option in the U.S.

The third factor is public opinion. Groups opposed to nuclear power have heightened public concerns about proliferation, reactor safety, waste and radiation. In many countries, particularly France and Japan, public opinion has been and continues to be supportive of nuclear energy, although the support in some countries appears to be waning.

The fourth reason nuclear energy is more aggressively pursued overseas than in the U.S. involves the disposition of spent fuel. The lack of a government facility to accept and dispose of spent nuclear fuel has caused additional capital and licensing costs for U.S. nuclear utilities for on-site spent fuel storage facilities. Many foreign countries do not share the U.S. government's policy on reprocessing of spent fuel. As a result, many countries are moving ahead with the reprocessing of spent fuel while the U.S. explores the policy and technical issues regarding the viability of geologic disposal.

The last factor hindering expanded use of nuclear energy in the U.S. involves the deregulation of the electric utility industry. In this environment, utilities and other electricity producers will openly compete for electricity sales with one another. As a result, U.S. utilities are eliminating or, at the very least, minimizing major capital outlays for new power plant construction, and evaluating the cost effectiveness of their current electrical generating assets in order to ensure future competitiveness.

COMMITTEE ON SCIENCE
U.S. HOUSE OF REPRESENTATIVES

Hearing
on

The Road from Kyoto—Part 2:

Kyoto and the Administration's Fiscal Year 1999 Budget Request

Thursday, February 12, 1998

Post-Hearing Questions
Submitted to

The Honorable David M. Gardiner
Assistant Administrator for Policy, Planning and Evaluation
U. S. Environmental Protection Agency

Post-Hearing Questions Submitted by Chairman Sensenbrenner

Global Warming and American's Health

Q1. On page 2 of your written testimony, you state:

"According to the Intergovernmental Panel on Climate Change, representing 2,000 leading scientific experts from around the world: 'Climate change is likely to have wide ranging and mostly adverse impacts on human health, with significant loss of life.' "

Please document this statement.

A1. IPCC provides an assessment of this topic in Chapter 18 (Human Population Health) of it's report *Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses* (1995 IPCC Working Group II Report). The chapter includes evaluation of a wide range of health impacts of climate change and references to the most important research on this topic that was available at the time of publication. The quote "Climate change is likely to have wide ranging and mostly adverse impacts on human health, with significant loss of life," is taken from page 13 of the Summary for Policy makers of the 1995 IPCC Working Group II Report and reflects the IPCC's assessment of the range of evidence on human health effects of climate change.

Q2. On page 2 of your written testimony, you state:

"There will be more frequent and more intense heat waves. Deaths directly attributable to heat waves in the U. S. could more than double by the middle of the next century."

Please document this statement.

A2. In its assessment of research on changes in extreme weather events that would accompany climate change, the IPCC found that small changes in mean climate, or small changes in climate variability, can produce relatively large changes in the frequency of extreme events. In particular, it is found that a general warming would tend to lead to an increase in extremely hot days. Research on this topic is reviewed in the IPCC's report *Climate Change 1995: The Science of Climate Change* (1995 IPCC Working Group I Report), pages 334-335.

Research on the health implications of increases in the frequency of extremely hot days, including increases in deaths directly attributable to heat waves, is discussed in the 1995 IPCC Working Group II Report (see Chapter 18, pages 563 and 570), *The Regional Impacts of Climate Change: An Assessment of Vulnerability* (see Chapter 8, pages 309-310), and "An Evaluation of Climate/Mortality Relationships in Large U.S. Cities and the Possible Impacts of a Climate Change" (*Environmental Health Perspectives*, Jan. 1997, pages 84-93).

Q3. On page 2 of your written testimony, you state:

"Hotter weather may lead to more frequent and more intense smog episodes, causing more deaths and illnesses from air pollution."

Please document this statement.

A3. Research has shown that ground level ozone, the primary constituent of smog, is affected by weather and climate and that there is a strong positive relationship between ozone concentrations and temperatures (see *The Regional Impacts of Climate Change: An Assessment of Vulnerability*, IPCC, 1998, pages 310-311). Other sources on the relationship between weather and air quality include: *Rethinking the Ozone Problem in Urban and Regional Air Pollution*, (National Research Council, National Academy Press, Washington, DC. Dec 1991), *National Air Quality and Emissions Trends Report, 1995* (EPA 454/R-96-005), *The Potential Effects of Global Climate Change on the United States, Report to Congress*, Appendix F: Air Quality (EPA-230-05-89-056), "Preliminary assessment of the effects of global climate change on tropospheric ozone concentrations" (Paper presented at the American Waste Management Association Specialty Conference: Tropospheric Ozone and the Environment II, November 1991), "Photochemical modeling analysis under global warming conditions" (AWMA paper No. 95-WP74B.02, Presented at the AWMA annual meeting, San Antonio, 1995), "The effects of climate change" in *Global Climate Change Linkages: Acid Rain, Air Quality, and Stratospheric Ozone* (ed. J. C. White. New York: Elsevier. 1989), and "Sensitivity of tropospheric oxidants to global chemical and climate change" *Atmospheric Environment* 23:519-532). For extensive documentation of health impacts associated with air pollution, see EPA's Air Quality Criteria Documents.

Q4. On page 2 of your written testimony, you state that:

"Unless we begin to act pest-borne tropical diseases may spread across our borders as warmer temperatures expand the range of disease-carrying insects and rodents."

Please document this statement.

A4. Sources on the potential northward spread of tropical diseases include *The Regional Impacts of Climate Change: An Assessment of Vulnerability* (see pages 312-313) and "Global Climate Change and Emerging Infectious Diseases" (*Journal of the American Medical Association*, Jan 1996, Vol. 275, pages 217-223).

Q5. On page 3 of your written testimony, you state:

"There will be more frequent and severe droughts and floods, causing deaths and injuries, as well as huge property losses."

Please document this statement.

A5. Research showing that climate change will intensify the hydrologic cycle is discussed in the 1995 IPCC Working Group I Report, (see Chapter 6, pages 335-336). This research indicates that the frequency of heavy rainfall events would increase. It also suggests that the frequency and length of dry spells may increase. Because of regional variations in how precipitation patterns would change, the IPCC concludes that prospects for more severe droughts and/or floods will increase in some places but decrease in others.

Floods are responsible for the majority of weather related deaths in the United States and are also responsible for injury, disease outbreaks due to breakdowns in sanitation services, and substantial property damage (see *The Regional Impacts of Climate Change: An Assessment of Vulnerability*, page 312). Severe drought has contributed to malnutrition and even starvation in many parts of the world (see IPCC Working Group II Report, page 571). Additional sources for information on impacts of floods and droughts include *The Public Health Consequences of Disasters* (ed. E.K. Noji. New York, Oxford: Oxford University Press. 1997) and *Climate Change and Human Health*. (Geneva, Switzerland: World Health Organization, 1996).

Q6. On page 2 of your written testimony, you state:

> **"Sea level will rise, exposing coastal areas to higher storm surges, with greater threats to health and safety, and more property damage. Salt water intrusion into coastal aquifers will endanger the drinking water supplies for millions of Americans."**

Please document this statement.

A6. The expectation that sea level will rise is documented in the EPA report "The Probability of Sea Level Rise" (1995) as well as the 1995 IPCC Working Group I Report. The increase in storm surges is explained in the 1984 book: "Greenhouse Effect and Sea Level Rise: A Challenge for this Generation" (edited by Barth and Titus; Van Nostrand Reinhold). The increased property damage is documented in a report to Congress by the Federal Emergency Management Agency entitled "Projected Impacts of Relative Sea Level Rise on the National Flood Insurance Program" (1991).

The statement about sea level rise endangering drinking water supplies was too narrowly focused on saltwater intrusion into coastal aquifers. Drinking water is also endangered by increased salinity in rivers and bays that will accompany sea level rise. Most of the documentation concerns increased salinity into surface waters. A 1985 report by EPA and the Delaware River Basin (out of print but posted the Internet at http://www.erols.com/jtitus/DE/DRBC.html#est4) estimated the increased salinity of the Delaware River, which could contaminate adjacent aquifers in New Jersey. Perhaps more importantly, when salinity levels in the Delaware are high, the report noted, an interstate compact requires that the supply from the river to New York City be shut off. A second salinity study appeared in EPA's 1989 Report to Congress on the Potential Effects of Global Climate Change on the United States; the study showed how higher salinity in the upper part of San Francisco Bay could impair the ability of the Central Valley Project to supply water to Southern California. EPA has not studied the water supply of Southern Florida in depth. Nevertheless, the 1989 report suggested that the Biscayne aquifer, which is the primary source of fresh water for Dade County, would be threatened by a one meter rise in sea level. The aquifer is currently recharged by wetlands and channel that are essentially at sea level. If the sea rises, those areas could become salty unless increased fresh water is supplied to those recharge areas. Such an increase in fresh water supplies, however, might not be possible due to declining fresh water availability -- unless the frequency of hurricanes increases. (See Report to Congress Appendix H, pages 2-10 and 2-11).

<u>**Global Warming and American's Environment**</u>

Q7. On page 3 of your written testimony, you state:

"By the end of the next century, rising sea levels could drown 4000 square miles of our ecologically-critical coastal wetlands. Five thousand square miles of dry land in states like Louisiana and Florida could be lost under water."

Please document this statement.

A7. Both of these statements come from an article in the journal Coastal Management, at 19:199-201 (1991) (also posted at http://www.erols.com/jtitus/Holding/NRJ.html#7000)

Q8. On page 3 of your written testimony, you state:

"Trout and other fish species could be entirely wiped out in many states -- depriving millions of our children and grandchildren of the simple pleasures of fishing."

Please document this statement.

A8. Several sources provide projections of climate change impacts on a number of freshwater fish species in rivers and streams. These studies are cited in the IPCC report *The Regional Impacts of Climate Change: An Assessment of Vulnerability*, pages 293-294. They are: (1) Eaton, J.G. and R.M. Scheller, 1996: Effects of climate warming on fish thermal habitat in streams of the United States. *Limnology and Oceanography*, 41, 1109-1115, which projects that an increase in summer mean air temperature of 2-6 degrees C will result in a reduction of about 50% in suitable habitat for cold-, cool- and selected warm-water species in the lower 48 states; and (2) US EPA, 1995: *Ecological impacts from climate change: an economic analysis of freshwater recreational fishing*, U.S. Environmental Protection Agency, Washington, DC, which projects that an increase in water temperatures due to climate change will result in a complete elimination of cold-water habitat for sites modeled in 5 to 10 states and severe reductions in habitat in 11 to 15 states, depending on the global circulation model (GCM) climate projection used.

Q9. On page 3 of your written testimony, you state:

"Forests and habitats will be lost in many states as climatic ranges shift faster than plant or animal species can migrate. Maple trees could die out in the Northeast, wiping out the fall colors of New England forever. Glaciers may disappear from Glacier National Park. About one-third of the Florida Everglades, now being protected at significant cost, has an elevation of less than 12 inches and is highly vulnerable to sea level rise."

Please document this statement.

A9. Research on the natural rates of migration of tree species is discussed in the 1995 IPCC Working Group II Report, pages 111-112. The research indicates that the rates of migration that would be necessary for tree species to remain in suitable climates can exceed the natural rates of migration for many species by an order of magnitude. The potential consequences for forest and habitat distributions are discussed in the Working Group II Report, pages 100-111, and in *The Regional Impacts of Climate Change: An Assessment of Vulnerability*, pages 275-279.

Research by Davis and Zabinsky (Changes in geographical range resulting from greenhouse warming: effects on biodiversity in forests, in *Global Warming and Biological Diversity*, R.L. Peters and T.E. Lovejoy, editors, 1992) indicate that warming and soil moisture losses could shift the climatic zone for sugar maple northward several hundred miles.

Since 1850 the area of Glacier National Park covered by glaciers has shrunk 70% while the number of glaciers has declined from more than 150 to about 50. Analyses of the USGS Biological Resources Division, Glacier Field Station, indicate that projected warming could cause the glaciers to completely disappear from the park by 2030.

<u>New "Energy Star" Partnership with Major TV and VCR Manufacturers</u>

Q10. On page 5 of your written testimony, you state:

> **The latest example, announced by Vice President Gore last month, is the new 'Energy Star' partnership, under which the major TV and VCR manufacturers will make products that use less energy. Your current TV uses energy even when it is turned off as circuits respond instantly when you press the remote control. The new machines will sharply cut the amount of energy used when off, reducing pollution by up to a million tons of carbon per year, and saving consumers up to $500 million per year on their electric bills. TVs and VCRs with the 'Energy Star' label soon will be in stores across the country.**

Q10.1. Please identify the TV and VCR manufacturers participating in this partnership.

A10.1. See attachment, "Participating Energy Star TV/VCR Manufacturers."

Participating ENERGY STAR TV/VCR Manufacturers:

JVC
LG (Lucky Goldstar)
Matsushita (Panasonic, Quasar)
Philips (Philips, Sylvania, Magnavox)
Radio Shack
Samsung
Sanyo Fisher
Sharp
Sony
Thomson (GE, RCA, ProScan)
Toshiba
Zenith

Q10.2. Please document the statement that "The new machines will sharply cut the amount of energy used when off, reducing pollution by up to a million tons of carbon per year, and saving consumers up to $500 million per year on their electric bills."

A10.2. See attachment -- "Energy Star TV/VCR Program Projections -- Carbon & Energy Bill Savings."

TV Calculations

Standby Mode Electricity Savings Per ENERGY STAR TV	
Baseline TV Standby Power (Watts):	5.9
ES TV Standby Power (Watts):	1.3
ES TV Standby Power Savings (Watts):	4.6
Hours Per Day TV Operates in Standby (hours):	19
Days Per Year Conversion (Days/Year):	365
Annual Standby Electricity Savings Per ES TV Unit (watt-hours/yr):	31,114
Annual Standby Electricity Savings Per ES TV Unit (kWh/yr):	31
Active Mode Electricity Savings Per ENERGY STAR TV	
Baseline TV Active Power (Watts):	75
ES TV Active Power (Watts):	70
ES TV Active Power Savings (Watts):	4.6
Hours Per Day TV Operates in Active (hours):	5.5
Days Per Year Conversion (Days/Year):	365
Annual Active Electricity Savings Per ES TV Unit (watt-hours/yr):	9,250
Annual Active Electricity Savings Per ES TV Unit (kWh):	9.3
Total Electricity Savings Potential for U.S. ENERGY STAR TVs	
Electricity Saved Per ES TV Unit (kWh/yr):	40
Number of TV units in the U.S. (TV units):	191,000,000
Electricity Saved by ES TV if 100% market penetration (kWh/yr):	7,709,464,964
Electricity Saved by ES TV if 100% mkt penetration (B kWh/yr):	7.7

VCR Calculations

Standby Mode Electricity Savings Per ENERGY STAR VCR	
Baseline VCR Standby Power (Watts):	5.1
ES VCR Standby Power (Watts):	3.6
ES VCR Standby Power Savings (Watts):	1.5
Hours Per Day VCR Operates in Standby (hours):	19
Days Per Year Conversion (Days/Year):	365
Annual Standby Electric Sav Per ES VCR Unit (watt-hours/yr):	10,239
Annual Standby Electric Sav Per ES VCR Unit (kWh/yr):	10
Active Mode Electricity Savings Per ENERGY STAR VCR	
Baseline VCR Active Power (Watts):	12.5
ES VCR Active Power (Watts):	11.0
ES VCR Active Power Savings (Watts):	1.5
Hours Per Day VCR Operates in Active (hours):	5.5
Days Per Year Conversion (Days/Year):	365
Annual Active Electricity Savings Per ES VCR Unit (watt-hours/yr):	3,044
Annual Active Electricity Savings Per ES VCR Unit (kWh):	3.04
Total Electricity Savings Potential for U.S. ENERGY STAR VCRs	
Electricity Saved Per ES VCR Unit (kWh/yr):	13.3
Number of VCR units in the U.S. (VCR units):	136,000,000
Electricity Saved by ES VCR if 100% market penetration (kWh/yr):	1,806,534,982
Electricity Saved by ES VCR if 100% mkt penetration (B kWh/yr):	1.81

TV/VCR Combo Calculations

Standby Mode Electric Savings Per ES TV/VCR Combo	
Baseline TV/VCR Combo Standby Power (Watts):	8.6
ES TV/VCR Combo Standby Power (Watts):	5.0
ES TV/VCR Combo Standby Power Savings (Watts):	3.7
Hours Per Day TV/VCR Combo Operates in Standby (hours):	19
Days Per Year Conversion (Days/Year):	365
Annual Standby Electric Sav Per ES TV/VCR Combo (watt-hrs/yr):	24,686
Annual Standby Electric Sav Per ES TV/VCR Combo (kWh/yr):	24.7
Active Mode Electric Savings Per ES TV/VCR Combo	
Baseline TV/VCR Combo Active Power (Watts):	52
ES TV/VCR Combo Active Power (Watts):	48
ES TV/VCR Combo Active Power Savings (Watts):	3.7
Hours Per Day TV/VCR Combo Operates in Active (hours):	5.5
Days Per Year Conversion (Days/Year):	365
Annual Active Electric Sav Per ES TV/VCR Combo (watt-hrs/yr):	7,339
Annual Active Electric Sav Per ES TV/VCR Combo (kWh):	7.3
Total Electric Savings Potential for ES TV/VCR Combos	
Electricity Saved Per ES TV/VCR Combo Unit (kWh/yr):	32
Number of TV/VCR Combo units in the U.S. (TV/VCR units):	8,000,000
Electricity Saved by ES TV/VCR Combo if 100% mkt (kWh/yr):	256,197,726
Electricity Saved by ES TV/VCR Combo if 100% mkt (B kWh/yr):	0.26

ENERGY STAR TV/VCR Program Projections--Carbon & Energy Bill Savings

Total Electric Savings Potential for ES TV/VCR Program	
Electricity Saved by ES TVs if 100% mkt pen (B kWh/yr):	7.7
Electricity Saved by ES VCRs if 100% mkt pen (B kWh/yr):	1.8
Electr Saved by ES TV/VCR comb if 100% mkt pen (B kWh/yr):	0.26
Total Electr Saved by ES TV/VCR Program if 100% mkt (B kWh/yr):	**9.8**
CO2 Savings Potential for ES TV/VCR Program	
Total Electr Saved by ES TV/VCR Program if 100% mkt (B kWh/yr):	9.8
Electricity to Carbon Conv (MMT Carbon/B kWh):	0.19
Carbon Saved by ES TV/VCR if 100% mkt pen (MMT Carbon):	**1.8**
Carbon to Carbon Dioxide Conv (MMT CO2/MMT Carbon):	3.7
Carb Dioxide Saved by ES TV/VCR if 100% mkt pen (MMT CO2):	**6.6**
Energy Bill Savings Potential for ES TV/VCR Program	
Total Electr Saved by ES TV/VCR Program if 100% mkt (B kWh/yr):	9.8
Residential Electricity Price ($/kWh):	$0.084
Energy Bill Savings by ES TV/VCR Program if 100% mkt pen ($):	**$822,819,044**

EPA's Existing climate change Action Plan (CCAP) Programs, Reductions in Greenhouse Gas Emissions, and Reduction in Annual U.S. Energy Expenditures

Q11. On page 5 of your testimony you say that "EPA's existing CCAP programs are expected to reduce U.S. greenhouse gas emissions by more than 40 million tons of carbon equivalent (MMTCE) in 1999. EPA's partnerships are expected to reduce annual U.S. energy expenditures by more than $25 billion by 2010."

A11. See attachment, 1998 Budget Narrative for 1999 impacts. See also the *U.S. Climate Action Report – 1997*, p. 112, which projects CCAP energy bill savings of $51.1 billion in 2010 at current program funding levels (copy of report attached). EPA's CCAP programs are responsible for more than 2/3 of the energy savings in 2010 (see Appendix for program-by-program description, 2010 energy savings, and agency affiliation).

<u>1999 Annual Performance Goals</u>

- Reduce U.S. greenhouse gas emissions by 40 million metric ton carbon equivalent (MMTCE) per year through partnerships with businesses, schools, state and local governments, and other organizations.

- Improve national air quality through reductions in criteria air pollutants, including annual reductions of over 90,000 tons of nitrogen oxides (NOx), a major contributor to ground-level ozone.

- Reduce U.S. energy consumption by over 45 billion kilowatt hours per year, including annual energy bill savings to consumers and businesses of over $3 billion. Encourage more widespread adoption of low greenhouse gas emitting technologies.

- Work with representatives of companies and industries interested in developing roadmaps of actions in the public and private sectors that can lead to improvements in energy use and reductions in GHG emissions.

- Conduct bilateral dialogues with 10-12 key developing countries to bring them toward meaningful participation under the Kyoto protocol. Reduce greenhouse gas emissions internationally.

- Advance the understanding and communicate the risks of climate change by working with state constituencies to assess economic and environmental impacts, develop strategies for reducing vulnerabilities, build the infrastructure to overcome existing impediments to mitigation, and implement technology-based options.

- Guide the development of the rules and guidelines to operationalize emissions trading, the Clean Development Mechanism, joint implementation, and early reduction credits.

- Assess greenhouse gas implications of major sector-based policies (e.g., utility deregulation, subsidy removal, revenue recycling, land use policy).

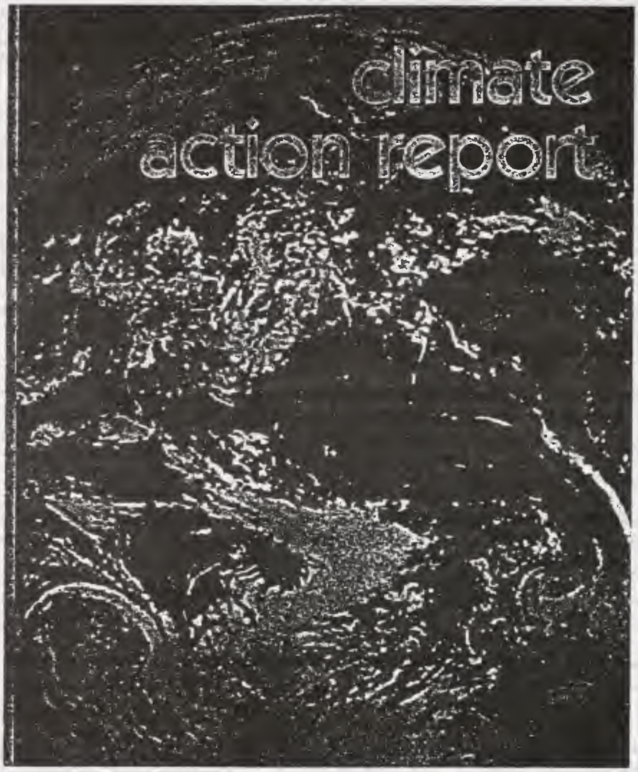
- Assess economic and technological advances to evaluate and establish domestic policies and measures to meet U.S. obligations under the Framework Convention on Climate Change and the December 1997 Kyoto Protocol.

- Demonstrate that an American family car can attain over 60 miles per gallon (MPG) on the Federal Test Procedure (FTP) without loss in utility, safely, and emissions control performance.

- Begin process to optimize prototype vehicle and to apply knowledge gained through PNGV program to trucks.

<u>Research</u>

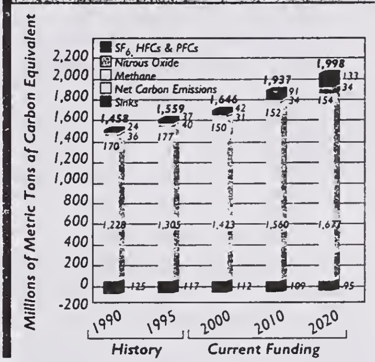
- Develop reports on problem formulation for ecosystem services sector assessment and on the use of climate change indicators.



1997 Submission of the United States of America
Under the United Nations Framework
Convention on Climate Change

Figure 4-3

Historical and Projected Greenhouse Gas Emissions 1990–2020



The results of this integrated analysis combined with a review of actual emission trends to date suggest that CCAP programs can be effective in reducing U.S. greenhouse gas emissions. CCAP actions reduce 4 percent of baseline emissions in 2000, 8 percent in 2010, and 10 percent in 2020. However, despite these substantial contributions, emissions will significantly exceed their 1990 levels in the year 2000.

- U.S. net greenhouse gas emissions in 1990 were 1,458 MMTCE.
- Estimated U.S. greenhouse gas emissions in 1995 were 1,559 MMTCE—6.9 percent above the 1990 level, and somewhat above the short-term increase projected in the first U.S. national communication, the 1994 *Climate Action Report*
- The updated "point estimate" for greenhouse gas emissions in the year 2000, assuming continued funding support for CCAP actions described in this report, comparable to the 1997 levels approved by Congress is 1,646 MMTCE—188 MMTCE above the 1990 level.
- Under current funding levels, planned actions are estimated to reduce greenhouse gas emissions by 76 MMTCE in the year 2000, compared to what they would have been otherwise (the baseline).
- Due to estimated energy savings initiated by CCAP actions to reduce greenhouse gas emissions, approximately $10.3 billion and $51.1 billion are saved in energy fuel use in 2000 and 2010, respectively.
- If funding were higher, as originally envisioned in the 1993 CCAP, estimated emission reductions would be about 30–40 MMTCE greater.
- While reductions from CCAP programs increase over time, projected greenhouse gas emissions still continue to grow over time, reaching 1,837 MMTCE by 2010 and 1,998 MMTCE by 2020.

The emission projections presented here include the full effect of the "foundation" actions contained in the earlier 1993 CCAP. The three foundation actions scored are: Climate Challenge, Climate Wise Companies, and State and Local Outreach. Emission reduction estimates are sensitive to the order in which foundation actions and other CCAP programs are counted. If reductions resulting from the activities of program participants that can be reflected in other actions or in the baseline are excluded, the estimated "incremental" emission reductions associated with the foundations are estimated to provide emission reductions of 11 MMTCE in 2000, 10 MMTCE in 2010, and 12 MMTCE by 2020. However, the full emission reduction contribution of these programs, which includes all reductions achieved through the activities of program participants, is substantially larger.

Assessing Current Estimates of Greenhouse Gas Emissions

As in the 1993 CCAP, an analytical team was established composed of members from all relevant federal agencies. The team was charged with reevaluating all 1993 CCAP actions and to include new actions as appropriate. A set of inputs was developed so that the modeling effort could be undertaken to account for potential overlap and synergistic effects among actions.

Two modeling scenarios were created: a Baseline scenario and an Action Plan scenario The Baseline scenario reflects expectations of private- and public-sector behavior based on legislation and federal programs already in effect. The Action Plan scenario combines all the policies contained in the baseline with the actions contained in the 1993 CCAP, as well as new actions developed since the publication of the original CCAP.

The projections contained in this section are derived from a set of specific assumptions about markets, technologies, and resources, such as growth rates in the gross domestic product (GDP) and world oil prices. Four main types of assumptions underlie the projections:

- *Economic factors,* including GDP growth rates, world oil prices, and other macroeconomic assumptions
- *Energy resources,* including proven reserves and undiscovered resources.
- *Market behavior,* reflecting the demand and supply decisions of energy-market participants, as influenced by energy prices, regulation, and policy programs
- *Technology factors,* which include information on the costs, performance, and commercial availability of energy-consuming, -converting and -producing technologies.

The Integrated Dynamic Energy Analysis Simulation (IDEAS) model was used as a tool for the integrated analysis of the energy-related actions. Table 4-3 presents a partial list of some of the key factors, containing both input assumptions and model results. This model has elements of both top-down and bottom-up modeling. The macroeconomic effects are combined with microeconomic, technology-specific representations of energy-service methods that link energy supply and demand through equilibrium market prices. Other sectors and gases were estimated independently.

Comparison of 1993 CCAP and 1997 CAR Greenhouse Gas Emissions

A comparison of the 1993 CCAP and the 1997 CAR reveals significant differences between the two sets of projections. These differences are caused by many factors, including the adoption of international accounting standards, the inclusion of newly identified greenhouse gases, updated global warming potential factors used to determine carbon-equivalent emissions, revised estimates of historical emissions, changes in baseline assumptions of emis-

appendix a: climate plan actions

Rebuild America

(Climate Plan Action 1)

This action is part of DOE's Commercial Buildings Program. In the year 2010, this broader program is expected to generate:

- Energy cost savings of $2.8 billion
- Energy savings of 0.42 quads
- Carbon-equivalent savings of 8.8 MMT

By accelerating cost-effective, energy-efficient investments in public housing, and in commercial and multifamily buildings, Rebuild America partnerships are expected to cut energy bills significantly, create local jobs, improve environmental quality, and provide more comfortable indoor environments that enhance the quality of life and worker productivity. For example, in the year 2000, Rebuild America partnerships plan to retrofit 2 billion square feet of commercial and housing floor space. This would put $3 billion into local economies and create $650 million in annual energy savings for building owners and occupants in the near future.

Partnerships are based on local needs and priorities, which provides community leaders a high level of flexibility in designing their Rebuild America programs. Any assembly of companies and organizations that commit to a community focus may form Rebuild America partnerships. Partners receive a customized set of products and services designed to meet their community's special needs as well as national recognition for innovative approaches to community-wide programs. A Rebuild America program representative works with the partners' team to ensure that timely and effective assistance is provided.

Achievements

As of March, 1997, Rebuild America is working with over 120 communities representing 38 states and territories.

- *Rebuild Boston* is incorporating water and energy efficiency into community enterprise zones.
- *Kansas City Energy Efficiency Partnership* is improving energy efficiency in schools and nonprofits over the bi-state, five-county metropolitan area.
- *Re-energize East Bay* is dramatically increasing the penetration of energy-efficiency technologies into the often overlooked small commercial market in the San Francisco Bay area.
- *Rebuild Colorado* is increasing the energy efficiency of the state's commercial and government buildings through performance contracting.

During the December 1996 Rebuild America Fall Forum, partners were enthusiastic about their achievements and about the success of the program in general. For example, through the Tennessee Department of Economic and Community Development, *Rebuild Tennessee* is targeting communities with 17,000 people or fewer—particularly small businesses—to achieve an estimated 30 percent energy cost savings per building retrofitted.

Contact: *Energy Efficiency and Renewable Energy Customer Service Center, 1-800-363-3732 (Domestic) or 703-287-8391 (International).*

Green Lights® & ENERGY STAR® Buildings

(Climate Plan Actions 1 & 2)

The *Climate Change Action Plan* expanded the Green Lights program. In the year 2010, the full Green Lights and ENERGY STAR Buildings programs are expected to generate:

- Energy cost savings of $11.3 billion
- Energy savings of 1.5 quads
- Carbon-equivalent savings of 23.9 MMT

EPA's Green Lights® and ENERGY STAR® Buildings programs are designed to improve the energy efficiency of commercial and industrial buildings. These buildings account for over 15 percent of all U.S. energy consumption, contributing significantly to greenhouse gas emissions and other air pollution. This pollution can be reduced through energy-efficiency investments that also reduce energy bills

Green Lights

Through the voluntary Green Lights program, EPA overcomes informational and other barriers preventing energy-efficiency investments. Green Lights partners are reducing their lighting energy consumption through cost-effective, energy-efficient lighting technologies. On average, investments in these technologies cut electricity consumption in half and provide a 35 percent rate of return due to the significant energy bill savings. EPA provides technical information and support and environmental recognition to participants who adopt these voluntary and profitable energy-efficiency measures Because lighting accounts for 35 percent of total electricity consumption in buildings, Green Lights has a substantial overall impact on U.S. energy consumption and greenhouse gas emissions.

ENERGY STAR Buildings

Expanding on the successful Green Lights program, EPA works with individual building owners, developers, and others through its voluntary ENERGY STAR Buildings program to encourage more comprehensive building upgrades. This program leads a building owner through a five-stage strategy to capitalize on system interactions that maximize energy savings at minimum cost. Green Lights is the first step of this strategy. EPA has successfully completed the ENERGY STAR Showcase Buildings program, in which charter partners demonstrated an average building-wide energy savings of 30 percent.

Achievements

The Green Lights and ENERGY STAR Buildings programs currently have over 2,300 participants, including small and large businesses, universities, and state and local governments

- Partners have already invested $1 billion on energy-efficiency improvements, with commitments for much larger investments in the near future
- Partners are saving over $300 million a year on their energy bills.
- Partners are preventing 700,000 metric tons of carbon-equivalent pollution annually, equivalent to eliminating the emissions from over 500,000 cars

Contacts: *EPA's ENERGY STAR Hotline, 1-888-782-7937 (Domestic) or 202-775-6650 (International)*

Cost-Shared Demonstrations of Emerging Technologies

(Climate Plan Action 4)

This action is part of DOE's Lighting and Appliance Research and Development Program. In the year 2010, this broader program is expected to generate:

- Energy cost savings of $3.1 billion
- Energy savings of 0.44 quads
- Carbon-equivalent savings of 9.3 MMT

DOE has longstanding experience working in collaboration with appliance and equipment manufacturers and distributors to promote the development of innovative, energy-conserving building equipment. Performance testing and new-product evaluation in commercial buildings are two of several areas enhanced through cost-shared demonstrations. DOE's cost-shared demonstration programs seek to achieve benefits primarily through reduced energy consumption for building appliances and HVAC (heating, ventilating, and cooling) systems.

By organizing projects that bring together manufacturers and prospective purchasers to test and evaluate prototype equipment, DOE expects to reduce the market risk perceived by the developer of new technology and provide users the opportunity to influence final design decisions. The result is greater investment in new, energy-efficient products, more rapid introduction of those products to the marketplace, and fewer failures of commercial introductions.

To achieve continuity and better coordination in its demonstrations, DOE has formed partnerships with groups of industrial and commercial firms having the potential to put emerging technologies to use. These Technology Partnerships include a consortium of hotel/motel chains and the National Association of Energy Service Companies.

Achievements

- Through a consortium of the hotel/motel industry, representing over 30 percent of U.S. hotel space, DOE and Red Lion Inn hotels demonstrated a new energy-saving system for large central laundries that allows reuse of hot laundry wash water.
- DOE and the U.S. Postal Service have embarked on a major demonstration of sulfur lamps, to introduce this technology to other similar facilities. Aircraft hanger lighting demonstrations are planned for Hill Air Force Base.
- Successful demonstrations of the "horizontal-axis" clothes-washing machines have prompted DOE and Maytag to demonstrate the water and energy savings of this beneficial technology to a small town that has severe water problems. Under a cooperative research and development agreement with Maytag and Oak Ridge National Laboratory, Maytag will replace washers in 90 homes throughout Bern, Kansas. To promote the environmental benefits of this technology in areas with severe water problems, DOE received co-funding from the Bureau of Reclamation that will be used to compare the energy and water consumption of the existing and new washers.
- DOE and the National Association of Energy Service Companies are improving the effectiveness of performance contracting as a means of introducing energy-efficient technology to the commercial sector.

Contact: *Energy Efficiency and Renewable Energy Customer Service Center, 1-800-363-3732 (Domestic) or 703-287-8391 (International)*

Operation, Maintenance and Training for Commercial Building Facility Managers and Operators

(Climate Plan Action 5)

This initiative is part of DOE's Best Practices Program. In the year 2010, this broader program is expected to generate:

- Energy cost savings of $1.2 billion
- Energy savings of 0.19 quads
- Carbon-equivalent savings of 3.9 MMT

DOE will use training programs and the educational infrastructure of the trades in its work to develop an operation and maintenance training curriculum highlighting energy Once in place, training will be available to new and experienced operators to assist in maintaining knowledge about energy-efficiency improvements for a highly transitory career field. DOE also draws upon the experience of the Federal Energy Management Program, that of state energy offices, low-income weatherization providers, utilities, and other successful programs currently underway, such as Rebuild America.

Achievements

- Surveyed existing programs and the successes and measures that have been used to evaluate training program effectiveness.

Contact: *Energy Efficiency and Renewable Energy Customer Service Center*, 1-800-363-3732 *(Domestic) or* 703-287-8391 *(International)*.

ENERGY STAR® Products

(Climate Plan Action 6)

The Action Plan expanded the ENERGY STAR Products program. In the year 2010, the full program is expected to generate:

- Energy cost savings of $10.2 billion
- Energy savings of 1.2 quads
- Carbon-equivalent savings of 23.7 MMT

DOE and the EPA are working to bring high-efficiency consumer products into American households and buildings. Products include those used for space heating and cooling, water heating, lighting, refrigeration, laundering, cooking, and other services.

Working with equipment manufacturers, DOE and EPA are using the ENERGY STAR® label to promote highly efficient products. Consumer education is an important part of the labeling activities. A national consumer education campaign is being developed to educate consumers about the important link between energy use and the environment. With the ENERGY STAR label, consumers will be able to easily identify products that save energy and money and help the environment. DOE has launched "ENERGY STAR Retailer" to further promote efficient products through point-of-purchase information, product labeling, sales force training, and corporate advertising.

Collaboratives formed with DOE are facilitating the development of initial markets for advanced technologies, for example, by encouraging large purchases. Large-volume purchases help reduce manufacturing costs through economies of scale in initial production.

Achievements

- Consumers and businesses prevented over one million metric tons of carbon-equivalent pollution in 1996, and saved over $400 million on energy bills due to ENERGY STAR equipment.
- Over 500 manufacturers are currently participating, offering over 13,000 product models that qualify for the ENERGY STAR label.
- Four major utilities have joined the program to promote ENERGY STAR appliances with retail chains in utility service territories.
- Over 920 retail stores now label ENERGY STAR refrigerators, dishwashers, and room air conditioners.
- Public housing authorities, including the New York Public Housing Authority, are about to purchase over 70,000 high-efficiency refrigerators for their apartment complexes.
- More than 70 builders and developers have committed to build over 10,000 ENERGY STAR Homes across the United States.

Contacts: *DOE's Energy Efficiency and Renewable Energy Customer Service Center*, 1-800-363-3732 *(Domestic) or* 703-287-8391 *(International), EPA's ENERGY STAR Hotline*, 1-888-782-7937 *(Domestic) or* 202-775-6650 *(International).*

Residential Appliance Standards

(Climate Plan Action 7)

This action is part of DOE's Lighting and Appliance Standards Program. In the year 2010, this broader program is expected to generate:

- Energy cost savings of $7.4 billion
- Energy savings of 0.96 quads
- Carbon-equivalent savings of 21.6 MMT

Residential consumers spend $110 billion each year on home appliances and equipment, such as refrigerators, water heaters, and air conditioners. As this equipment is replaced, large savings opportunities are available from the purchase of high-efficiency equipment. The Energy Policy Act of 1992 directs DOE to develop mandatory energy-efficiency standards for residential appliances. DOE must review these standards in accordance with a statutorily set schedule to determine whether the standards are stringent enough. Energy and carbon emission reductions from this action will be a direct result of more stringent appliance efficiency standards.

The Residential Appliance Standards program creates higher energy-efficiency levels for eleven product categories of residential appliances. The program enlists the participation of manufacturers, trade associations, environmental groups, utilities, government agencies, residential appliance retailers, and others in public rulemaking processes to set these new standards.

Achievements

- Three-Product Rulemaking—In September 1993, DOE published an Advance Notice of Proposed Rulemaking in the *Federal Register* regarding energy-conservation standards for central air conditioners and heat pumps; furnaces, and refrigerators, refrigerator-freezers, and freezers. The three-product rule has since been amended into three separate rules. The standard, which applies to refrigerators, refrigerator-freezers, and freezers, was published in July 1995.
- Clean Three Rulemaking—DOE has conducted analyses on clothes washers, clothes dryers, and dishwashers and held a workshop in July 1995 to discuss the results with stakeholders.
- Eight-Product Rulemaking—The eight-product rule was divided into several separate rules. One rulemaking applies to room air conditioners, gas and oil water heaters, direct heating equipment, kitchen ranges and ovens, mobile home furnaces, and pool heaters. A proposed television rule has been withdrawn.
- A congressional moratorium imposed on new standards during 1996 has ended. DOE expects to issue final rules for improved efficiency standards for refrigerators and room air conditioners in 1997. An Advanced Notice of Proposed Rulemaking for clothes washers is also due out in 1997.

Contact: *Energy Efficiency and Renewable Energy Customer Service Center, 1-800-363-3732 (Domestic) or 703-287-8391 (International)*

Energy Partnerships for Affordable Housing

(Climate Plan Actions 8 & 11)

This initiative is part of DOE's Residential Buildings DOE's Residential Buildings Program. In the year 2010, this broader program is expected to generate:

- **Energy cost savings of $0.4 billion**
- **Energy savings of 0.06 quads**
- **Carbon-equivalent savings of 1.2 MMT**

Energy Partnerships for Affordable Housing is designed to improve the energy efficiency and affordability of public and privately owned single-family and multifamily housing for low- to moderate-income families throughout the nation. Its main goal is to create local and community partnerships that will collectively commit to installing energy-efficiency improvements in at least one million low-income housing units by the year 2000.

Begun as a joint initiative between DOE and the Department of Housing and Urban Development, the program establishes voluntary collaborations with state and local governments, utilities, and the housing development and financing industries that can provide resource-efficient and affordable housing in new and revitalized buildings. Major program components include: (1) formal partnerships with local public housing authorities to improve large portions of the housing they own and operate; (2) work with community-based housing providers, builders, architects, and associations to showcase and promote efficient whole-building design scenarios throughout their communities; and (3) close collaboration with retailer program efforts to foster appliance efficiencies. The partnership also works with those who establish guidelines for Home Energy Rating Systems

Program goals are expected to be reached by making technical assistance available to community-based housing providers for the application of whole-building design and rehabilitation specifications that can achieve 20 to 30 percent efficiency gains over current practice. DOE and the National Association of Housing and Redevelopment Officials have united under DOE's Energy Partnerships for Affordable Housing program.

Achievements

- DOE initiated partnerships with public housing authorities and community housing organizations in Chicago, Atlanta, Boston, Baltimore, and Los Angeles, with one goal being a 30 percent reduction in utility bills.
- DOE, EPA, and Habitat for Humanity are working together to improve the energy and resource efficiency of the over 3,000 homes Habitat has built in the United States.
- DOE is funding seven states (AK, AR, CA, CO, MI, VT, and VA) to overcome the barriers to the use of energy-efficient mortgages.

Contact: *Energy Efficiency and Renewable Energy Customer Service Center, 1-800-363-3732 (Domestic) or 703-287-8391 (International).*

Cool Communities

(Climate Plan Action 9)

This initiative is part of DOE's Building Systems Program. In the year 2010, this broader program is expected to generate:

- **Energy cost savings of $1.0 billion**
- **Energy savings of 0.15 quads**
- **Carbon-equivalent savings of 2.9 MMT**

Cool Communities aims to reverse problems associated with urban heat islands by developing community partnerships to create a market for highly reflective exterior surfaces on buildings and roads, in combination with urban tree planting as a cost-effective energy-efficiency measure.

Private-sector involvement in Cool Communities is an integral part of the program. The nonprofit conservation organization American Forests is DOE's and the U.S. Forest Service's primary partner in this program. Utility companies, through their participation in the Climate Challenge program, also are partners. Roofing, pavement, coatings, and landscaping industries, as well as other federal agencies participate in product development and marketing.

Overall Achievements

- As of March 1997 there are 10 designated Cool Communities.
- In its next revision, the National Energy Performance Standards for Buildings (American Society of Heating, Refrigeration and Air-Conditioning Engineers) will give energy-conservation credits for cool roofs and shade trees. Similar credits will be offered in the California Title 24 building standard.
- South Coast Air Quality Management District in California accepted Cool Communities strategies as the most cost-effective single measure in the reduction of smog. Consideration is being given to include "cool" technology in a NO_x and smog offset trading market.
- The American Society for Testing and Materials is standardizing procedures for rating roofs and pavements for reflectivity. A new "Solar Reflectance Label" will help consumers evaluate the energy efficiency of cool products.

Selected Community Achievements

- Austin, Texas—Initiated "Trees for Energy," in which utility companies, landscaping industry professionals, and local government officials collaborated on incentive rebates for planting community trees.
- Atlanta, Georgia—Broadcasts heat-island reports on the evening weather and used the 1996 Summer Olympics to publicize demonstrations of Cool Communities technologies.
- Frederick, Maryland—Estimates energy savings of $1 million annually from existing trees and roofs, with a potential tripling of savings by using more "cool" technologies.
- Dade County, Florida—Is raising funds from the state's sale of panther and manatee license plates to reestablish trees destroyed by Hurricane Andrew.
- Davis–Monthan Air Force Base in Tucson, Arizona—Was awarded the Federal Energy Efficiency Landscape Award for Cool Communities accomplishments.
- National Air Station, Oceana—Is planning tree-planting, pavement, and roofing projects.

Contacts: *Energy Efficiency and Renewable Energy Customer Service Center, 1-800-363-3732 (Domestic) or 703-287-8391 (International), Rita Schoeneman, USDA, Forest Service, Cooperative Forestry, 202-205-1612*

Updating State Building Codes

(Climate Plan Action 10)

This action is part of DOE's Building Standards and Guidelines Program. In the year 2010, this broader program is expected to generate:

- Energy cost savings of $4.0 billion
- Energy savings of 0.55 quads
- Carbon-equivalent savings of 12.7 MMT

Updating and implementing building energy codes is often the most cost-effective means of overcoming market barriers to energy efficiency. These codes eliminate inefficient construction practices and technologies at little to no increase in first cost and significant energy cost savings.

DOE provides technical and financial support to states in updating and implementing the energy-efficiency provisions of their codes. Competitive, cost-shared, incentive grants are provided to assist states in leveraging their own programs and those of their utility and building industry partners to update their codes and train code officials, designers, and builders in how to use them. DOE develops materials and tools to make energy codes easier to use and administer, and disseminates them to the states. DOE also develops core training materials and fosters industry partnerships with states to carry out training.

DOE's goal is to reduce total emissions and energy use in new buildings by 35 percent by the year 2000, from 1990 levels.

Achievements

- Twenty-seven states have adopted and implemented residential energy codes that meet or exceed the 1992 Model Energy Code. These state codes govern 54 percent of U.S. residential construction.
- Twenty-five states have adopted and implemented commercial building energy codes that meet or exceed the building industry consensus energy code, ASHRAE/IESNA 90.1–1989. These state codes govern 61 percent of U.S. commercial construction.
- Over 1,000 architects, engineers, builders, and code officials have been trained in how to comply with updated state codes.
- DOE has developed a set of materials and tools that make it easy to design and build to the Model Energy Code. Called MEC*check*, this set has been disseminated to over 10,000 people in 20 states.
- A parallel set of materials, COM*check-EZ*, has been developed for low-rise commercial buildings (three stories or fewer), which comprise the majority of U.S. commercial building.
- DOE has formed partnerships with a number of product manufacturers to assist states in training designers and builders.

Contact: *Energy Efficiency and Renewable Energy Customer Service Center, 1-800-363-3732 (Domestic) or 703-287-8391 (International).*

Construction of Energy-Efficient Buildings

(New Climate Plan Action)

In the year 2010, this initiative is expected to generate:

- Energy cost savings of $0.5 billion
- Energy savings of 0.1 quads
- Carbon-equivalent savings of 1.1 MMT

The Rebuild America and ENERGY STAR Buildings programs are effectively improving the energy efficiency of existing commercial and industrial buildings. Additional, long-term energy savings and greenhouse gas reductions can be achieved by improving the energy efficiency of new commercial and industrial buildings. By 2010, one-fifth of all energy consumption in commercial and industrial buildings is projected to be from buildings that are built after 2000. Through this joint initiative, DOE and EPA will expand their voluntary programs in the buildings sector by promoting energy efficiency in the construction of new buildings.

Despite the wide availability of reliable, energy-efficient technologies and building designs, most builders and architects are not taking advantage of these energy cost-saving opportunities Several barriers in the current buildings market perpetuate the construction of inefficient buildings. Most notably, builders and designers usually do not own and operate their buildings and are, therefore, not responsible for paying the energy bills. Increasing the construction costs to achieve long-term energy savings, even when there is a quick payback of only a couple of years, is not feasible unless purchasers and financiers of buildings have clear and reliable information regarding the cost savings they can expect.

DOE and EPA will work with builders, architects, owners and operators, and the financial community to encourage and recognize the construction of energy-efficient buildings. Working with these industries, DOE and EPA will develop a system to differentiate buildings that offer energy cost savings from typical, inefficient buildings. Rebuild America has already begun working with the American Institute of Architects and many other partners to reach these goals. ENERGY STAR Buildings has developed an energy-efficiency building program that currently focuses on retrofits to existing buildings. Under this action, the agencies will jointly develop a program that most effectively improves energy use in new buildings.

Contacts: *DOE's Energy Efficiency and Renewable Energy Customer Service Center, 1-800-363-3732 (Domestic) or 703-287-8391 (International). EPA's ENERGY STAR Hotline, 1-888-782-7937 (Domestic) or 202-775-6650 (International).*

Superwindow Collaborative

(New Climate Plan Action)

This initiative is part of DOE's Windows and Glazings Program. In the year 2010, this broader program is expected to generate:

- Energy cost savings of $0.8 billion
- Energy savings of 0.11 quads
- Carbon-equivalent savings of 2.3 MMT

DOE's Superwindow Collaborative is expected to double the energy efficiency of the average window sold in 2005 In achieving its goals, the collaborative is expected to improve the thermal properties of the windows sold in terms of both their heating and cooling energy properties: reducing the average U value of windows sold from 0.65 to 0.25 in heating climates, and switching from clear to spectrally selective cool glazings in the southern part of the country.

Every year residential windows in the United States are responsible for about 2.0 quads of energy use and 40 MMTCE. If all residential buildings used currently available—but not extensively deployed—high-performance window technologies, annual window energy use could be reduced by 1.2 quads, and annual carbon emissions by about 18 MMT. Certain fundamental constraints limit the achievement of this technical potential: (1) the window-selection and -specification process, by which end users (e.g., home owners, builders, renovators, and architects) are capable and motivated to choose the energy-efficient window technologies; and (2) the availability of high-performance glazing and window technologies and the ability of the industry to produce such technologies at affordable prices and in adequate volumes

As an offshoot of one of DOE's buildings research programs, the Superwindow Collaborative supports highly leveraged industry–user–government teams in transforming the market and industry toward production and use of energy-efficient windows.

Another industry team will be coordinated through the Primary Glass Manufacturers Association. Growth in market penetration of Low-E and other high-energy-performance windows has slowed and is now about one-third of the market DOE–industry teams will work to re-accelerate this growth to more than double the penetration of high-energy-performance window systems. These teams will strive to upgrade their specific technologies—e.g., vinyl windows and glass-coating processes and technologies

Superwindow Collaboratives will produce and provide tools and information products for window manufacturers, along with detailed training by producer and user teams.

Some of the private- and public-sector partners DOE will be collaborating with are the National Fenestration Rating Council, utilities, window component manufacturers, glass manufacturers, window system manufacturers, states, retailers, and the architect–engineer community

Contact: *Energy Efficiency and Renewable Energy Customer Service Center,* 1-800-363-3732 *(Domestic) or* 703-287-8391 *(International)*

Expand Markets for Next-Generation Lighting Products

(New Climate Plan Action)

In the year 2010, this initiative is expected to generate:

- Energy cost savings of $0.4 billion
- Energy savings of 0.1 quads
- Carbon-equivalent savings of 0.7 MMT

This action is expected to expand markets for energy-efficient lighting products through coordinated federal programs primarily targeting residential lighting. The action is based on a comprehensive strategy to convert incandescent lighting to energy-efficient alternatives by delivering a portfolio of products to meet a range of needs over an extended time horizon. The objectives are to promote:

- use and improvement of compact fluorescent products (CFLs),
- conversion of high-energy-using fixtures to dedicated CFL fixtures, and
- filling-in a key product gap with a low-cost, drop-in replacement for standard incandescent light bulbs.

A first step already taken under this action at the federal level is a procurement effort jointly led by Office of the Secretary of Defense and DoD's Defense Supply Center–Richmond, implemented with the joint support of the DOE and EPA. DoD is seeking to purchase low-cost, drop-in replacement products for standard-sized light bulbs that provide at least a 30 percent energy savings, compared to traditional incandescent lamps. DoD is serving as the "anchor buyer" in an effort that ultimately will involve state and local agencies and private-sector procurement offices. Once new products have been introduced to the market through this mass procurement, additional efforts will be implemented to further enhance their market penetration.

Contacts: *Tracy Narel, EPA, Atmospheric Pollution Prevention Division, 202-233-9145; Bill Noel, DOE, 202-586-6149.*

Fuel Cells Initiative

(New Climate Plan Action)

This initiative is part of DOE's Space Conditioning Program. In the year 2010, this broader program is anticipated to generate:

- Energy cost savings of $1.1 billion
- Energy savings of 0.13 quads
- Carbon-equivalent savings of 3.5 MMT

The Fuel Cells initiative offers a unique technology that can revolutionize the way building power, heating, cooling, and hot water are generated and maintained. No other cogeneration system can generate electricity, provide heat, and hot water with the low emission, low noise, and high efficiency of the fuel cell.

Fuel cells have a large potential to reduce carbon emissions in power generation and buildings. Among other energy sources, fuel cells can be powered by hydrogen. They produce both electrical and thermal energy through an electrochemical reaction, and they have exceptionally high efficiencies with water as the only by-product. The principal obstacle to widespread use of this technology is its high cost, although a very large potential exists for reducing those costs.

DOE's initial goal is to develop low-cost, 50-kilowatt fuel cell technologies that use reformed methane to produce hydrogen fuel to power commercial buildings. DOE will research methane steam reforming for the Proton Exchange Membrane (PEM) fuel cell; low-cost, high-performance membranes; CO-tolerant catalysts; and lightweight, high-conductivity electrodes (bi-polar plates).

DOE will also develop lower-cost materials and fuel reformers to produce the hydrogen fuel. Toward this end, DOE will work closely with researchers, fuel cell manufacturers, and the gas industry to develop and deploy low-cost PEM fuel cells to demonstrate their high efficiency, low noise, and low carbon production.

Within the next four years, DOE plans to complete: a methane reformer breadboard system, system-level tests, field testing, and a prototype for installation in buildings. Since fuel cells in buildings would differ considerably from those used in automobiles, the 50-kilowatt fuel cell will be developed in conjunction with DOE's advanced automotive technology program.

Achievements

Four contracts are in place that focus on: membrane research, natural gas reforming, catalyst development for CO tolerance, and bi-polar plate development.

Contact: *Energy Efficiency and Renewable Energy Customer Service Center, 1-800-363-3732 (Domestic) or 703-287-8391 (International).*

Motor Challenge

(Climate Plan Actions 12 & 13)

In the year 2010, Motor Challenge is expected to generate:

- **Energy cost savings of $0.34 billion**
- **Energy savings of 0.07 quads**
- **Carbon-equivalent savings of 5.8 MMT**

Since electric motor-driven system applications account for more than 70 percent of U.S. industrial energy consumption, Motor Challenge is geared at harnessing the tremendous potential energy cost savings that will accrue once system inefficiencies are identified and reduced. Motor Challenge is a voluntary partnership program between DOE and industry to promote the adoption of a systems approach to developing, purchasing, and managing motors, drives, and motor-driven equipment, thereby increasing energy efficiency, enhancing productivity, and improving environmental quality.

Motor Challenge is comprised of four integrated program elements: Industry Partnerships (trade associations and industry groups); Allied Partnerships (non–end-user companies, along with suppliers, distributors, utilities, etc.); Excellence Partnerships (end-user industrial companies); and Showcase Demonstrations (technically focused projects at industrial plants). These partnerships aim to develop and deliver new tools, information, best practices, and industry case studies to assist manufacturers in making more informed management decisions about motor-driven systems.

In addition to program elements, Motor Challenge offers numerous products and services. These include MotorMaster Plus, an electric-motor decision and management software tool; a periodic newsletter, *Turning Point*; showcase demonstration project case studies; pumping system optimization workshops; and the Information Clearinghouse, which maintains the Motor Challenge Web Page (http://www.motor.doe.gov) and responds to partner inquiries.

The Showcase Demonstrations bring together motor system users, equipment manufacturers, utility companies, and state energy offices to host the design, engineering, installation, and operation of projects using technology and engineering to optimize electric motor systems.

Achievements

- The Motor Challenge program was officially launched in October 1993, with 44 organizations designated as Charter Partners.
- As of June 1997, 2,000 organizations had enlisted with over 125 Allied Partners (suppliers, distributors, utilities, and state agencies) who are disseminating Motor Challenge products, tools, and software to thousands of industrial end users.
- The Information Clearinghouse has responded to over 800 calls a month requesting information and technical assistance. More than 250 downlink sites with an audience of over 8,000 viewed the "Efficient Motor Systems: Strategies for Success" teleconference on May 23, 1995.
- DOE has completed 10 showcase demonstrations, and has 15 ongoing projects representing an industry investment of $10 million. The estimated annual energy savings represents 100 million kilowatt-hours a year, or the equivalent amount of electricity supplied to over 5,000 homes a year.

Contact: *Motor Challenge Information Clearinghouse, 1-800-862-2086 (Domestic) or 703-287-8391 (International).*

Industrial Assessment Centers

(Climate Plan Action 15)

In the year 2010, Industrial Assessment Centers (IACs) are expected to generate:

- Energy cost savings of $0.4 billion
- Energy savings of 0.08 quads
- Carbon-equivalent savings of 1.9 MMT

Over 80 percent of industrial energy is consumed by manufacturing. Smaller manufacturing firms rarely have in-house expertise or staff to address energy-efficiency and waste-minimization improvements.

Since 1976, DOE has sponsored energy audits for small- and medium-sized manufacturers. Conducted by the IACs at 30 universities across the country, these audits provide recommendations to help manufacturers control costs and improve energy efficiency

In addition to evaluating industrial energy use, IACs make recommendations for minimizing wastes and for improving productivity, and conduct energy-productivity and waste-reduction analyses. Under the IAC program, teams of engineering faculty and students perform the industrial assessments. Each school completes approximately 25 assessments a year for plants within a 150-mile radius of its campus. Partnering plants must be in compliance with standard industrial codes 20–39, must have gross sales below $75 million at the plant site, must employ fewer than 500 people, must have a utility bill of $75,000–$1,750,000, and must lack the technical skill to perform the assessment on their own

Achievements

- Since 1976 the program has conducted over 7,000 energy assessments
- Approximately 2,100 students who have participated in the program through their university have received energy-efficiency and waste-management training. This experience gives them access to better opportunities upon graduation
- Via the Internet, utilities, manufacturing firms, and the general public may access IAC results and recommendations from a data base that holds the results of all assessments since 1981.
- A training manual and "Self Assessments" workbooks were produced for both small and large plants. These materials are available on the Internet at http://www.oit.doe.gov/access iac.html

Contact: *Energy Efficiency and Renewable Energy Customer Service Center, 1-800-363-3732 (Domestic) or 703-257-8391 (International).*

NICE³

(Climate Plan Action 16)

In the year 2010, NICE³ is expected to generate:

- Energy cost savings of $0.4 billion
- Energy savings of 0.09 quads
- Carbon-equivalent savings of 2.1 MMT

National Industry Competitiveness Through Energy, Environment, and Economics (NICE³) promotes innovation, energy efficiency, clean production, and economic competitiveness in industry through one-time matching grants of up to $425,000. The program funds state and industry partnership proposals that will develop and demonstrate advances in energy-efficiency and clean-production technologies.

Successful projects demonstrate industrial applications of energy-efficient technologies that reduce costs to industry and prevent pollution in the manufacturing sector, with emphasis on the aluminum, chemicals, forest products, glass, metal casting, petroleum refining, and steel sectors. They identify and implement efficiency improvements in material inputs, processes, and waste streams to enhance U.S. industrial competitiveness. The total federal value of current projects is at least $20 million, with an average private cost share of $3.68 of private investment per federal dollar.

Achievements

- With fiscal year 1996 funds, 17 projects were funded in 15 states, with $6.2 million in federal funds and $12.0 million co-funded by each state–industry partnership to produce the next wave of cost-effective, pollution-prevention technologies that will spawn further innovation as project successes come to fruition.
- As a result of NICE³, Caterpillar demonstrated to over 90 attendees at an open house that paint sludge from water-washed overspray could be recovered and recycled. While continuing to use the technology in-house, Caterpillar is also negotiating with potential vendors to market the technology to industry, thus potentially exceeding the energy and environmental benefits originally projected.
- Beta Corporation of Oregon, a small business, has sold approximately 20 units of its Hydrochloric Acid Recovery System, a closed-loop, on-site recovery system for galvanizers and small- to medium-sized steel manufacturers.
- Pegasus Technologies Neural Networks has sold several installations of its Real-Time Neural Networks for Combustion Optimization system. The computerized monitoring system optimizes combustion settings for minimal NO_x and reduced SO_2 and CO_2 emissions, while simultaneously maintaining or improving plant thermal efficiency. These installations have saved over one trillion Btus of energy.

Contact: *Energy Efficiency and Renewable Energy Customer Service Center,* 1-800-363-3732 *(Domestic) or* 703-287-8391 *(International).*

WasteWi$e

(Climate Plan Action 16)

EPA's WasteWi$e program encourages businesses to set voluntary waste-prevention and -recycling goals that they can achieve cost-effectively. The businesses agree to report on progress toward achieving those goals. The Pay-As-You-Throw program (PAYT), on the other hand, encourages communities and municipalities to consider charging for waste disposal according to weight or volume. PAYT is a proven financial incentive for citizens to reduce and recycle their waste.

EPA source-reduction and recycling efforts are intended to reduce greenhouse gas emissions by (1) reducing methane emissions from the decay of waste in landfills, (2) increasing carbon sequestered by forests, and (3) reducing emissions resulting from extracting and processing virgin materials and manufacturing products. Beyond emission reductions, additional benefits include preservation of natural resources from reduced extraction and processing of virgin materials; reduced waste disposal; reduction in air, water, noise, and other pollution associated with waste disposal and manufacturing; reduced costs of municipal solid waste management, and jobs and income created by new recycling enterprises.

Achievements

- After only three full years of operations, WasteWi$e boasts over 535 business partners who are reducing and recycling increasing quantities of waste. While 1996 results are not yet available, in 1995 WasteWi$e partners conserved nearly 344,000 tons of materials through waste prevention—a 40 percent increase over 1994 reported figures. In addition, partners quadrupled the reported amount of materials collected for recycling to over four million tons. Partners also helped create stronger markets for collected recyclables by purchasing more than two million tons of recycled-content products in 1995. WasteWi$e is opening membership to tribal, state, and local governments for the first time in 1997.
- Program highlights in 1996 included completion and distribution of a PAYT Tool Kit (containing, among other things, a guide and workbook for determining how to establish rates for household trash disposal) and completion of a digital spreadsheet for use by solid waste planners in developing rates to charge for waste disposal. Also in 1996, significant progress was made in completing a comprehensive training video on Pay-As-You-Throw for use by solid waste planners. As of the end of 1996, EPA estimates over 3,000 Pay-As-You-Throw programs are in place nationwide.

Contact: *Clare Lindsay, EPA, Office of Solid Waste, 703-308-7266*

Improve Efficiency of Fertilizer Nitrogen Use

(Climate Plan Action 17)

Improving the efficiency of fertilizer use will result in lower emissions of nitrous oxide (N_2O) from microbial activity occurring in the soil and lower CO_2 emissions from electricity and natural gas consumption during the manufacture of fertilizer. The program is expected to expand activity to develop models that focus on trace gas exchange related to the bacterial nitrification and denitrification processes. These models will be used to improve the efficiency of nitrogen use, while maintaining an efficient and productive agricultural system. Demonstration projects and an information campaign will ensure widespread application of improved management practices.

Achievements

- Extensive collection of data from farmers' fields has been completed for testing the USDA Agricultural Research Service's NLEAP model for determining the efficiency of nitrogen use. Comparisons show efficiencies in small grain > potatoes > lettuce. Rotations of small grains with potatoes and lettuce, and proper management of irrigation, increase efficiencies in these systems. Wheat and rye, when used as winter cover crops, mitigate nitrogen losses by scavenging nitrogen lost from the shallower root systems of lettuce and potatoes. The scavenger winter-cover crops protect water and soil quality by reducing wind erosion and increasing the cycling and efficient use of nitrogen. NLEAP is a technology-transfer management tool capable of evaluating the effects of sequential crops on water quality and on the cycling and efficient use of nitrogen.
- The NLEAP model was extended to predict N_2O emissions from agricultural soils under a range of management and weather conditions. Field testing of the model in Colorado has shown that simulated N_2O losses are consistent with measured values. A prototype version of the model has been delivered to USDA's Natural Resources Conservation Service (NRCS) for field testing nationally. Joint Agricultural Research Service research is continuing to evaluate and apply the model nationwide
- Of the 18 demonstration projects NRCS established in 1995, four continue to receive funding for substituting organic sources of nitrogen (e.g., legume cover crops or manure) for commercial nitrogen fertilizer and alternative methods of manure application to maximize nutrient utilization by plants.
- NRCS is evaluating nitrogen management systems for corn, cotton, potatoes, and rice that minimize gaseous emissions of N_2O with the model NLEAP. Ten states are currently participating. NRCS will create a data base of this information for its conservationists in the field and for others who provide nutrient management planning assistance to farmers.

Contacts: *Ron Follett, USDA, Agricultural Research Service,* 970-490-8200, *Charles Lander, USDA, Natural Resources Conservation Service,* 202-690-0249.

Transportation Partners

(Climate Plan Action 20)

This initiative is intended to reduce the growth in vehicular travel through voluntary adoption of local and regional transportation strategies that provide better, cheaper, and more numerous transportation choices for citizens. These strategies are (1) community design or redevelopment measures that encourage walking, biking, and transit; (2) market-based measures that, for example, reduce parking subsidies or transmute them into transit benefits, or that increase the cost of peak-hour travel relative to nonpeak travel; and (3) applications of telecommunications and other technologies that can eliminate the need to travel (telecommuting or teleservices), or that increase the market viability of transit.

Transportation Partners promotes the voluntary efforts of citizens and elected officials to develop innovative transportation projects and plans that address transportation needs, economic growth, environmental quality, and equity. The highly decentralized program encourages and recognizes local commitments to better transportation systems and provides a wide range of technical, strategic, and outreach assistance to ensure effective implementation.

The travel reductions that will be achieved by local partners brought into the program in its initial year are currently being estimated but are at least in the tens of millions of miles per year. A current program priority is implementing an ongoing evaluation strategy that will more precisely assess emission reductions achieved by this program. The benefits of Transportation Partners are expected initially to accrue slowly after the program's 1995 implementation and grow exponentially over the next several years.

Achievements

- Transportation Partners recruited 291 Project Partners working to improve local environments and transportation systems.
- The Principal Partner Local Government Commission held two major regional conferences on transportation for livable communities, which attracted over 1,000 participants.
- EPA's first annual "Way to Go!" awards were presented to eight outstanding local transportation innovators from the public and private sectors
- The Transportation Action Network ("TransAct"), a comprehensive electronic information and assistance service, was launched by the Principal Partner Surface Transportation Policy Project. TransAct provides activists and transportation professionals with Internet access to a wide range of resources and peer contacts. See www.transact.org
- The program co-sponsored the 1996 Rail-volution Conference in Washington, D.C., which was attended by over 600 civic representatives, transportation professionals, and developers. This annual conference has become the principal annual meeting for promoters of progressive transportation solutions at the local and national levels

Contact: *Paula Van Lare, EPA, Energy & Transportation Sectors Division,* 202-260-3729

National Telecommuting Promotion

(Climate Plan Action 21)

Both the *National Performance Review* (NPR) and the *Climate Change Action Plan* (CCAP) identify telecommuting as a possible means to reduce traffic congestion, air pollution, greenhouse gas emissions, energy consumption, and accidents. The U.S. Department of Transportation (DOT) was designated the lead agency under the NPR and CCAP to promote and evaluate telecommuting in the federal government and in state and local agencies and the private sector.

Achievements

- Created a specialized training program and training materials on telecommuting for DOT supervisors and managers.
- Inaugurated the National Telecommuting Initiative, designed to implement new telework programs in up to 30 metropolitan areas.
- Initiated development of promotional campaign and field visits to states and federal regional offices to provide support in launching new telecommuting programs.
- Initiated research on successful telecommuting programs in the public and private sectors, and work on publicizing information on telecommuting, as mandated by Congress in the DOT appropriations legislation for fiscal year 1996. A report on successful programs will be generated.
- Initiated development of the *Telecommuting Planning Manual* for state and local agencies, which was completed in June 1997.

Contact: *DOT, Office of the Assistant Secretary for Transportation Policy,* 202-366-4813

Seasonal Gas Use for the Control of NO_x

(Climate Plan Action 24)

EPA promotes seasonal switching toward the use of low-carbon natural gas—particularly in the summer—in utility coal and oil plants and in industrial facilities. This innovative, low-cost strategy is expected to reduce carbon emissions and NO_x emissions (which contribute to smog formation). The action is tied to rules and guidance issued in response to NO_x Reasonable Available Control Technology (RACT) requirements, the Economic Incentive Program, and State Implementation Plans related to National Ambient Air Quality Standards attainment under Title I of the Clean Air Act. EPA is working to encourage the use of natural gas through incentive-based, innovative programs that allow for less costly control strategies and provide stronger incentives for the development and implementation of innovative emission-reduction technologies.

Achievements

- EPA has continued the policy established in a guidance document that promotes the summer use of natural gas in utility coal and oil plants and in industrial facilities as a NO_x-reduction strategy.
- Twelve states in the Northeast and the District of Columbia (the Ozone Transport Region—) adopted a memorandum of understanding committing to a significant reduction in NO_x emissions from large sources (especially electric utilities) beyond RACT requirements. Utilities may comply with NOx requirements by switching to natural gas during the summer

Contact: *Tracy Terry, EPA, Air and Energy Policy Division, 202-260-2875*

Renewable Energy Commercialization—Biomass

(Climate Plan Action 26)

This initiative is part of DOE's Biomass Power Research and Development Program. In the year 2010, this broader program is expected to generate:

- Energy cost savings of $0.9 billion
- Energy savings of 0.43 quads
- Carbon-equivalent savings of 8.9 MMT

New renewable-energy capacity of nearly 175 megawatts by the year 2001 is expected as biomass gasification demonstrations succeed and rural development proposals ensue. With twice as many partners as projected, DOE's Biomass Program is realizing the potential that near-term demonstration of integrated biomass power systems can have on technology deployment.

In addition, DOE's rural collaborative efforts are addressing the need for growing and harvesting dedicated energy feedstock for electricity generation. By using renewable, domestically produced biomass feedstocks, these systems can provide positive economic and environmental benefits over traditional fossil-fuel-based energy options. And as baseload and intermediate-load power-production options, these systems have great market-penetration potential, with the ability to compete in the largest segment of the U.S. electric utility market.

The major elements of this program include the Biomass Power for Rural Development initiative, a collaborative of DOE, USDA, and two advanced technology demonstrations—the Vermont Gasifier Project and the Hawaii Biomass Gasifier Facility—both of which involve the evaluation of advanced gasification/gas turbine systems.

Achievements

- In 1993, 10 private-sector consortia were formed.
- In December 1994, DOE, in collaboration with USDA, issued a request for proposal for integrated biomass power demonstration projects. DOE received more than 350 requests for the solicitation. In response, private-sector consortia, representing more than 100 organizations from 25 states, proposed a total of 1,000 megawatts of biomass-generating capacity and the dedication of up to 250,000 acres to biomass energy feedstock production. The three proposals selected through this competitive process will demonstrate cost-competitive, renewable biomass electricity generation from dedicated energy feedstocks by 2001. In total, these three projects will generate over 150 megawatts.
- The Vermont Gasifier Project will operationally demonstrate high-efficiency, "indirect" biomass gasification/gas turbine systems in 1998, and will produce over 15 megawatts of biomass power from wood resources

Contact: *Energy Efficiency and Renewable Energy Customer Service Center, 1-800-363-3732 (Domestic) or 703-287-8391 (International).*

Renewable Energy Commercialization—Geothermal Power

(Climate Plan Action 26)

This initiative is part of DOE's Geothermal Energy Research and Development Program. In the year 2010, this broader program is expected to generate:

- Energy cost savings of $0.3 billion
- Energy savings of 0.15 quads
- Carbon-equivalent savings of 3.5 MMT

To increase the competitiveness of geothermal power and educate utility companies on the advantages of geothermal power, DOE led a collaboration of the geothermal industry, investor-owned and municipal utilities, and the federal government to develop the Geothermal Power Initiative. The initiative has accelerated commercial operation of cost-shared geothermal projects, including the development of a pipeline to deliver treated municipal wastewater to raise reservoir pressure and increase the volume of hydrothermal fluids at the Geysers field in California; and cost sharing of initial power plants (on the order of 10 megawatts) at new geothermal fields

Geothermal power has important advantages over fossil-fired, electric-generation technologies, including negligible atmospheric emissions and fixed fuel costs. These programs are designed to bring additional geothermal electrical power generation on line within the next three years and to stimulate new power development into the next century.

Partners include (1) the geothermal industry, which has helped plan the collaborative effort and has responded to solicitations for cost-shared projects, and (2) utilities, which will provide the market for geothermal power purchases Interagency collaborators include the U S Department of the Interior's U S Forest Service

Achievements

- Using system designs and components developed by the DOE/industry technology-development partnership formed in the mid–1970s, the U S. geothermal industry has deployed about 1,000 megawatts of new geothermal electric facilities at 12 sites in the western United States
- A solicitation for cost-shared geothermal power projects was published in the *Federal Register* in March 1995.
- The Idaho Operations Office is reissuing a solicitation to identify a recipient who will conduct a small-scale commercial demonstration project during the fall of 1997.

Contact: *Energy Efficiency and Renewable Energy Customer Service Center, 1-800-363-3732 (Domestic) or 703-287-8391 (International).*

Renewable Energy Commercialization—Geothermal Heat Pumps

(Climate Plan Action 26)

This initiative is part of DOE's Geothermal Energy Research and Development Energy Research and Development Program. In the year 2010, this broader program is expected to generate:

- Energy cost savings of $0.5 billion
- Energy savings of 0.31 quads
- Carbon-equivalent savings of 7.2 MMT

The goal of this action is to realize "400,000 by the year 2002" in annual geothermal heat pump (GHP) sales. With 120 utility partners representing a majority of the nation's electric customers, this collaborative effort is on track for reaching this goal.

GHPs are among the most efficient technologies for providing heating, cooling, and water heating to residential and commercial buildings. However, they will not likely emerge as a mainstream heating, ventilation, and air conditioning option without concerted efforts to increase cost-competitiveness, public knowledge of their availability and merits, and the GHP industry's ability to design, install, and maintain GHP systems.

To address these needs, the Geothermal Heat Pump Consortium—comprised of electric utilities, GHP manufacturers, trade groups, environmental organizations, EPA, and DOE—has launched a "Geothermal Heat Pump Technology Demonstration and Market Mobilization Program." The program is designed to reduce energy consumption, greenhouse gas emissions, and space-conditioning costs for residential and commercial building users by lowering costs associated with initial GHP installations. To build public confidence in the technology and to avoid the use of many different names, the industry has elected to use the name Geo Exchange to "brand" the technology.

Achievements

- In conjunction with the 1996 Olympics in Atlanta, GHPs were installed in a number of buildings.
- In 1996, 14 utilities committed over $12 million in jointly funded GHP pilot and demonstration programs.
- In 1995 and 1996, over 4,000 Geo Exchange units were installed at Louisiana's Fort Polk Army Base. Statistically valid data show an annual savings of over 30 million kilowatt-hours and a summer-peak-demand reduction of 6.7 megawatts.

Contact: *Energy Efficiency and Renewable Energy Customer Service Center, 1-800-363-3732 (Domestic) or 703-287-8391 (International).*

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Renewable Energy Commercialization—Photovoltaics

(Climate Plan Action 26)

This initiative is part of DOE's Photovoltaics Systems Research and Development Program. In the year 2010, this broader program will generate:

- Energy cost savings of $0.06 billion
- Energy savings of 0.03 quads
- Carbon-equivalent savings of 0.6 MMT

DOE is working with the photovoltaic (PV) industry and others to reduce the price of electricity from PV systems, raise the lifetime of PV modules to 30 years, and increase PV module efficiencies DOE's program efforts focus on three major elements: market conditioning, joint ventures, and strategic technological research.

This action is being accomplished via four major projects: TEAM-UP, a market-acceleration program taking place in cooperation with the Utility Photovoltaic Group (UPVG); Renewable Energy Technology Analysis, a program to evaluate and promote understanding of long-term costs and benefits of PV technologies; a program that supports state-level planning; and a program to support consumer advocates who will evaluate the cost-effectiveness of PV installations. TEAM-UP will address both grid-connected applications of PV, as well as the grid-independent PV applications.

Achievements

- DOE's most active partner, the Utility Photovoltaic Group (UPVG), has grown into an 84-member organization representing all sectors of the electric utility industry and more than 45 percent of U.S. kilowatt-hour electricity sales.
- The UPVG awarded eight contracts for market-development efforts for grid-independent PV applications, which collectively identified 130 utilities with potential to participate in market-development efforts.
- One grid-independent application team receiving UPVG support, the Photovoltaic Services Network, represents more than 40 electric utilities in 12 states in the West and Midwest
- To date, the UPVG has awarded contracts to 19 teams, installing $50 million in new PV installations with a 4:1 industry/DOE cost-shared ratio. The project includes more than 1,640 individual PV systems totaling more than 8 megawatts, all connected to electric utility systems. The awards will result in new PV installations in more than 25 states nationwide.
- DOE supported the installation of a 340-kW PV roof system, the world's largest PV roof system, in the 1996 Olympic Natatorium in Atlanta.

Contact: *Energy Efficiency and Renewable Energy Customer Service Center,* 1-800-363-3732 *(Domestic) or* 703-287-8391 *(International).*

Renewable Energy Commercialization—Wind

(Climate Plan Action 26)

This initiative is part of DOE's Wind Program. In the year 2010, this broader program is expected to generate:

- Energy cost savings of $0.6 billion
- Energy savings of 0.26 quads
- Carbon-equivalent savings of 5.2 MMT

Interest in wind power technology is high, but the current lack of a well-established infrastructure for manufacturing, installing, and servicing wind turbines presents a great obstacle to commercialization. Representatives from interested parties in wind deployment—such as electric utilities, utility trade organizations, wind turbine equipment manufacturers, consumer groups, environmental groups, and state and federal regulators—joined with DOE to form a wind collaborative whose members selected the name National Wind Coordinating Committee (NCC). Its goal is to ensure the responsible use of wind energy in the United States—an increasingly important goal, as wind energy provides the environmental benefit of zero-emission electricity generation.

DOE's principal support includes: expansion of the existing Turbine Verification Program, cost-shared deployment of wind energy to enhance infrastructure development, assessment of wind resources, and avian wind research. The Wind Turbine Verification Program provides co-funding support to a consortium that evaluates prototype wind turbines in commercial utility settings (6 megawatts or larger). The commercialization initiative shares the cost of developing full-fledged wind power plants (25 megawatts or more). The Utility Resource Assessment Program promotes wind energy by assisting utilities in evaluating possible sites for wind deployment. Finally, the Avian Research Program implements a broad-based scientific program to assess the impacts of wind development on avian populations

Achievements

- In December 1994, DOE (through the National Renewable Energy Laboratory) issued a solicitation seeking cost-shared wind-farm projects. Eight proposals for more than 200 megawatts were received. In September, NREL announced its selection of three projects totaling 61 megawatts.
- To represent the interests of the nation's electric utilities and independent power producers in the NCC, the Utility Wind Interest Group was formally organized and incorporated.
- With the assistance of DOE cost-sharing, the Utility Wind Interest Group, Inc., selected six of nine possible proposals to collect and analyze wind data at multiple sites across the nation. Participating electric utilities are providing 65 percent of the funding. Two projects with 13-megawatt capacity are moving forward.
- DOE will provide technical assistance to construct wind turbine power plants in Minnesota and Iowa through NREL. Project planning advice and performance reports will be provided for the next five years.

Contact. *Energy Efficiency and Renewable Energy Customer Service Center,* 1-800-363-3732 *(Domestic) or* 703-257-9391 *(International).*

Integrated Resource Planning

(Climate Plan Action 27)

Utility companies, the state regulators who oversee them, and legislators need new analytical and management tools to make sound decisions in an increasingly complex and competitive utility environment. The Integrated Resource Planning (IRP) program addressed this need.

This initiative began in 1994 by supporting research on policy and planning tools that support both supply and demand issues. The program expanded to include an increasing emphasis on outreach and education to put IRP tools in the hands of state and regional regulators, legislators, and utility managers. The IRP program served state utility commissions, state energy offices, independent power producers, and utilities. Key partnerships included the National Association of Regulatory Utility Commissioners (NARUC), the National Conference of State Legislatures (NCSL), trade associations (including renewable-energy producer organizations), and energy-efficiency advocacy groups.

The IRP program consisted of the Education Voucher Program, which provides educational assistance for state regulators and their staff; the Electric Utility Restructuring Partnership, which provides information and analysis to states in formulating options for effective utility restructuring; DOE's IRP in Public Power Project, in conjunction with the American Public Power Association and the National Rural Electric Cooperative Association, which provides technical assistance to small public power utilities that wish to use IRP and demand-side management in their management operations; and support for state IRP initiatives through NARUC and NCSL.

Due to funding cuts, this program was terminated. The following achievements were realized before the program's termination.

Achievements

- Of the 335 applications for educational vouchers the program received during its operation, the program awarded more than 230 vouchers worth approximately $250,000. The vouchers were used for a variety of purposes, including conducting renewable-energy workshops and obtaining technical resources, such as software and technical reports to enhance IRP-related decision making. In most cases, these resources would not have been accessible to state agencies without the IRP–DSM voucher program.
- In its first two years before its termination and during the budget appropriations process, the program sponsored more than 30 seminars to provide state regulators with a fundamental knowledge of IRP.
- IRP's national Performance-Based Rate-Making design workshop attracted more than 100 participants.
- The program provided funding for more than 100 national studies of IRP and IRP-related issues that have been delivered to all states.

Contact: *Energy Efficiency and Renewable Energy Customer Service Center, 1-800-363-3732 (Domestic) or 703-287-8391 (International).*

Energy-Efficient Distribution Transformer Standards

(Climate Plan Action 29)

U.S. electric utilities use an estimated 40 million distribution transformers. Although utility distribution transformers collectively have a high rate of efficiency, they account for approximately 61 billion kilowatt-hours (kWh) of the 229 billion kWh of energy lost annually in the delivery of electricity The Energy Policy Act of 1992 required DOE to determine if distribution transformer standards are warranted. This initiative was established to evaluate the feasibility of efficiency standards for electric distribution transformers, targeting single-phase distribution transformers up to 833 kilovolt ampere (kVa) and three-phase transformers up to 2,500 kVa

To conduct this evaluation, DOE established partnerships with electric utility associations, distribution transformer manufacturers associations, and commercial and industrial facility owners/operators. DOE will assess whether distribution and efficiency standards are technologically feasible, economically justified, and result in significant energy savings. If the findings support formal development of efficiency standards, DOE will promulgate rulemakings for testing, standards, and labeling requirements.

Achievements

- In February 1995, DOE submitted a report to Congress on *The Feasibility of Replacing or Upgrading Utility Distribution Transformers During Routine Maintenance*
- In July 1996, DOE published *Determination Analysis of Energy Conservation Standards for Distribution Transformers.*

Contact: *Energy Efficiency and Renewable Energy Customer Service Center, 1-800-363-3732 (Domestic) or 703-287-8391 (International).*

ENERGY STAR® Transformer Program

(Climate Plan Action 30)

In the year 2010, the ENERGY STAR Transformers program is expected to generate:

- Energy cost savings of $0.8 billion
- Energy savings of 0.1 quads
- Carbon-equivalent savings of 1.4 MMT

Approximately 40 million distribution transformers are in service on utility transmission lines. These transformers, which convert power from high voltages used in the transmission of electricity to lower voltages used in homes and businesses, lose approximately 61 billion kilowatt-hours of energy annually.

The ENERGY STAR® Transformer Program seeks to reduce these losses by encouraging utilities to overcome barriers to purchasing cost-effective and energy-efficient transformers and by encouraging manufacturers to produce high-efficiency transformers using available technologies. In addition, EPA is working with industry members to develop technical tools to analyze highly complex transformer use and sizing decisions. Finally, EPA will encourage utilities and regulatory commissions to reduce any regulatory barriers that prevent the implementation of cost-effective, supply-side efficiency investments, such as efficient transformers.

The ENERGY STAR Transformer Program was launched successfully in April 1995, with over 85 percent of transformer manufacturers already participating The program is on target to achieve its CCAP goal for saving over 2 billion kilowatt-hours of electricity in the year 2000. The program has developed new marketing strategies that demonstrate the benefits of high-efficiency transformers in a competitive electric industry. In addition, the program has released several technical tools and reports that are focusing attention on distribution efficiency and assisting with efficient transformer selection.

Achievements

- The program currently has 41 Utility Partners who purchase approximately 10 percent of the distribution transformers sold annually to utilities
- The program currently has 9 Manufacturing Partners representing more than 85 percent of the distribution transformer manufacturing market.

Contact: *Pete South, EPA, Atmospheric Pollution Prevention Division, 202-233-9482*

Green Power Network

(New Climate Plan Action)

DOE has developed an Internet-based information network known as the Green Power Network. Accessible through DOE's Office of Energy Efficiency and Renewable Energy home page, the network provides and exchanges information on successful green power programs and provides network links to utilities, power marketers, public entities, and consumer and environmental organizations that have already developed or are interested in developing green power programs. The provision of this information and the information links will help encourage electricity suppliers and customers to form green power supply and buyer groups.

The electric power industry is undergoing unprecedented change, with the regulated monopoly structure of the industry becoming increasingly subject to competition. Wholesale competition has resulted in a price-dominated market in which renewables, which generally have high front-end cost structures, are being disadvantaged.

At the same time, retail competition should lead to a greater number of service options for electricity customers, some of which will include renewable energy. Since utility customers and public opinion surveys have identified strong public support for the development of clean energy sources, the ability of customers to express a market preference for renewable-energy sources can be a key driving force in moving greater amounts of renewables into the market. Already, several utilities have developed customer-oriented "green pricing" programs, and a handful of municipalities have taken action to acquire renewables-based power to serve their loads.

These "green marketing" approaches employ market-based mechanisms to promote greater adoption of renewables and are entirely compatible with ongoing attempts to introduce greater competition into the generation and delivery of electricity. However, only a handful of power providers and customers have attempted to tap into this market. There is a need to more broadly disseminate information and experiences with green power programs, so that other organizations and market entities can apply this information to design and implement successful green power programs.

The Green Power Network is a site dedicated to providing information and points of contacts on green power programs and activities. DOE has worked with electricity-sector organizations in the development of the web site, and is linking to other green power-oriented businesses and organizations. This web site can be accessed at http://www eren.doe.gov/greenpower. To qualify for a link to the web site, businesses and organizations should have an existing green power program underway.

Contact: *Energy Efficiency and Renewable Energy Customer Service Center,* 1-800-363-3732 *(Domestic) or* 703-287-8391 *(International).*

Natural Gas STAR

(Climate Plan Action 32)

The Action Plan expanded the Natural Gas STAR program. In the year 2010, the full program is expected to generate:

- Methane savings of 55 billion cubic feet
- Energy cost savings of $100 million
- Carbon-equivalent savings of 6.0 MMT

Through the Natural Gas STAR program, EPA encourages natural gas companies to adopt cost-effective technologies and practices that reduce emissions of methane, a potent greenhouse gas. In March 1995, the program was expanded from the transmission and distribution sectors to include the production sector. In addition to providing implementation support, EPA provides partners with public recognition and works to remove unjustified regulatory barriers. Companies submit an implementation plan to EPA after becoming a partner and implement the plan over the next three years.

By working with the natural gas industry, Natural Gas STAR has identified nine cost-effective, methane-reducing best management practices (BMPs). EPA has developed a series of tools to help partners implement these BMPs, including an implementation guide measurement program and a series of "lessons learned" studies that communicate superior implementation of BMPs by program partners.

Achievements

- In 1996, the Natural Gas STAR program reduced methane leakage from natural gas pipelines by over one million metric tons of carbon-equivalent emissions.
- The expanded program includes 65 corporate partners representing:
  - 65 percent of transmission company pipeline miles,
  - 32 percent of distribution company pipeline miles, and
  - 33 percent of U.S. natural gas production.
- The American Gas Association, the American Petroleum Institute, the Interstate Natural Gas Association, the International Centre for Gas Technology Information, the National Association of Regulatory Utility Commissioners, the Natural Gas Supply Association, and the Southern Gas Association have endorsed the Natural Gas STAR program.
- In addition, the Gas Research Institute endorsed the program in April 1994, pledging $4 million of its annual budget to projects that reduce methane emissions.

Contact: *Rhone Resch, EPA, Atmospheric Pollution Prevention Division, 202-233-9793*

Landfill Rule and Landfill Methane Outreach Program

(Climate Plan Actions 33 and 34)

LANDFILL METHANE OUTREACH PROGRAM

In the year 2010, the Landfill Methane Outreach Program is expected to generate:

- Methane savings of 26 billion cubic feet
- Energy cost savings of $50 million
- Carbon-equivalent savings of 2.9 MMT

Landfills are the largest source of U.S. anthropogenic methane emissions. Because methane is a fuel, landfills also represent a tremendous energy resource. Through the Landfill Methane Outreach Program (LMOP), launched in December 1994, EPA is encouraging landfills across the nation to capture and use their landfill gas emissions. This voluntary effort works hand-in-hand with EPA's landfill New Source Performance Standards and Emissions Guidelines (also known as the "Landfill Rule") to promote cost-effective reductions in methane emissions. Promulgated in March 1996, the Landfill Rule requires large landfills to capture and combust their landfill gas emissions. By providing potential project partners reliable technical and economic information on the opportunities to use landfill gas as a fuel, creating innovative financing opportunities, and demonstrating the many benefits of converting landfill gas to energy, the LMOP is helping landfills affected by the Landfill Rule to achieve the maximum benefit at the lowest cost.

EPA works with state energy and environmental agencies, landfill owners, utilities, trade associations, and industry to lower the barriers to landfill gas-to-energy project development. The LMOP disseminates reliable information, identifies project opportunities, and creates momentum for increasing the economically and environmentally beneficial use of landfill gas.

Together the LMOP and the Landfill Rule are expected to achieve reductions of over 35 MMTCE in the year 2000.

Achievements

- Allies include 18 state agencies in 13 states, 15 utilities, and more than 70 industry representatives, including project developers, equipment suppliers, financiers, and landfill gas end users.
- 6 State Ally workshops have been held, and several more are scheduled.
- A wide range of focused products have been developed and distributed, including:
  - a project development handbook;
  - profiles of landfills that are good candidates for energy recovery in 20 states;
  - primers outlining key state regulatory and incentive information for 3 states;
  - software to evaluate the most attractive project options for specific landfills, including estimation of costs and benefits; and
  - fact sheets and issue papers providing guidance on critical issues.
- Provided Landfill Rule guidance and workshops for state agencies and affected landfills.
- Catalyzed development of at least 24 new landfill gas-to-energy projects.

Contact: *Tom Kerr, EPA, Atmospheric Pollution Prevention Division, 202-233-9768.*

Coalbed Methane Outreach Program

(Climate Plan Action 35)

In the year 2010, the Coalbed Methane Outreach Program is anticipated to generate:

- Methane savings of 29 billion cubic feet
- Energy cost savings of $55 million
- Carbon-equivalent savings of 3.2 MMT

In 1990, methane emissions associated with coal mining operations accounted for approximately 18 percent of human-related U.S. methane emissions. Launched in spring 1994, the Coalbed Methane Outreach Program is reducing these emissions by (1) working with the coal industry and other stakeholders to identify and remove obstacles to increased investment in coalbed methane recovery projects, and (2) raising awareness of opportunities for profitable investments.

Currently, at least 13 U.S. mines are recovering and using methane. Under this program and as a result of the Energy Policy Act of 1992, an additional 47.8 trillion Btus of methane energy are expected to be recovered annually, representing approximately 25 new or expanded projects by 2000.

Coal mine methane projects must meet site-specific technical and market conditions to be profitable. Many general market barriers and opportunities can either hinder or encourage projects. The program works on a mine-by-mine basis to identify and overcome the specific technical, legal, market, and financial barriers to project implementation. Program staff works directly with the coal mine staff to prepare technical, financial, and market analyses that identify profitable project opportunities. The program also works with developers, state and local governments, and potential gas markets to identify and overcome the various generalized technical, market, financial, and legal barriers.

Achievements

- During 1995 and 1996, at least seven new or expanded-use projects were initiated at coal mines. These projects included introducing coalbed methane into the nation's natural gas pipeline supply, generating power from abandoned mine gas, and using methane to replace coal as a fuel source for drying at a coal mine preparation plant. In 1996, a contract was signed to upgrade lower-quality mine gas from two active mines and two abandoned mines for pipeline injection—the first project of its kind.
- EPA worked with operators of several mines to develop detailed technology and financial assessments of the profitable opportunities for coal mine methane projects. These assessments are catalyzing project developments.
- EPA developed guides for state, local, and federal assistance programs that pinpoint sources of loans, grants, and technical assistance for profitable coal mine methane projects. In addition, EPA prepared a comprehensive guide for private-sector financing of coal mine methane projects.
- EPA evaluated and reported on technological options for enhanced coalbed methane recovery, use, and markets that have lowered the informational barriers to profit-making coalbed methane projects.
- In 1996 and 1997 EPA hosted two national conferences that focused on key financial and policy issues related to coalbed methane project development.

Contact: *Karl Schultz, EPA, Atmospheric Pollution Prevention Division,* 202-233-9468

Methane Recovery Systems—Coal Mining

(Climate Plan Action 36)

DOE's Office of Fossil Energy and EPA (Climate Plan Action 35) have jointly supported outreach, cost-shared demonstrations, and market-entry projects to investigate and apply technologies for capturing and using methane emitted during coal mining. Methane is highly explosive and, when emitted into the mine workings during coal mining operations, can be a serious safety hazard. Within DOE the Office of Fossil Energy is primarily responsible for the methane recovery program. Management of the program is coordinated with EPA; the National Mining Association; fuel cell, gas turbine, and internal combustion engine manufacturers; private industry; utilities; and others.

The program has supported partnership teams, led by the coal industry, that are developing the application of evolving and existing technologies for recovery and use of coal mine methane gas. The program has three operational phases: Phase I—feasibility study of the proposed program and solicitation of cost-shared demonstrations, Phase II—detailed design of the proposed demonstrations, and Phase III—implementation of pilot demonstrations.

The program involves partners in planning, implementation, and financing. Coal mining and natural gas production industries are included as potential partners for gas recovery and sales. Natural gas transmission, electrical power, and coal mining companies are the potential users of the recovered gas. Power-generation equipment vendors may join in partnerships to provide the hardware for recovery and use. Local communities may also be partners for providing local fuel or power in the community or for industrial/energy parks.

Achievements

- Five Phase II coal mine methane projects with multiple partners are currently completing detailed designs for field recovery and use demonstration efforts in 1998. Project partners include a coal operator, a utility, an engineering firm, and an engine manufacturer.
- Two of the project efforts have partly completed the design of the field demonstrations and are beginning to recover initial quantities of coal mine methane.
  - One of these projects involves DOE, Northwest Fuel Development, an active coal mine and an electric utility in Harrison County, Ohio. The present installed capacity of this facility is 500 kilowatts, or about one-quarter of the coal mine's total power consumption. The existing generators are driven by automobile-derivative internal combustion (IC) engines. Design work is currently underway in cooperation with Energy Research Corporation to develop a demonstration unit with a capacity of 300 kilowatts. It is anticipated that the use of the fuel cell will allow for more flexible operation of the IC engines.
  - The second project intends to use methane contained in the mine ventilation exhaust and gas from gob wells drilled into the strata just above the longwall mining face. The total methane emissions from the Emerald mine (Greene Co., Pa.) are capable of generating 50 or more megawatts. The specific hardware for the prototype is being determined, and a test plan is being developed for operation.

Contact: *DOE, Office of Fossil Energy, 202-586-4756, or DOE Federal Energy Technology Center, 304-285-4547.*

Methane Recovery Systems—Landfills

(Climate Plan Action 37)

Municipal landfills are the single largest source of methane emissions nationwide, generating over one-third of the nation's methane greenhouse gas. DOE, through its methane capture research, development, and demonstration activities, and EPA, through its public outreach (Climate Plan Action 34), have worked jointly to maximize methane gas use and recovery from landfills.

The Solid Waste Management Association of North America (SWANA) has been a key partner with DOE in the design and delivery of this initiative. SWANA is the largest professional organization representing landfill gas recovery. The group has been conducting meetings and symposia on landfill gas recovery since the late 1970s.

Due to funding cuts, DOE's participation in this program was terminated. The following achievements were realized before the program's termination.

Achievements

- A workshop was held to identify technical barriers to the recovery and use of landfill-generated methane gas, resulting in an information base for planned activities.
- Two projects—the study and verification of landfill gas prediction models and the development of "manuals of practice" for gas recovery—were initiated as a result of the workshop.
- A Notice of Intent was published in 1994 in the *Commerce Business Daily* to determine the level of interest of industry and stakeholders in cost-shared projects for landfill gas recovery and use. Thirty-one responses were received, indicating strong support from private-sector landfill operators.

An increased knowledge base will result from the two study initiatives and from the relationships that have been established with the professional community through collaboration with SWANA. The verified model for the prediction of methane gas levels at landfill sites will provide better information to landfill operators trying to estimate the amount of gas they can expect to recover over time.

Contact: *Energy Efficiency and Renewable Energy Customer Service Center,* 1-800-363-3732 *(Domestic) or* 703-287-8391 *(International).*

AgSTAR Program

(Climate Plan Action 38)

In the year 2010, the AgSTAR program is expected to generate:

- **Methane savings of 16 billion cubic feet**
- **Energy cost savings of $30 million**
- **Carbon-equivalent savings of 1.8 MMT**

Launched at the White House Conference on Climate Change in the spring of 1994, this cooperative effort of EPA, USDA, and DOE is a voluntary pollution-prevention program with the livestock industry. EPA and USDA work with livestock producers to capture the methane released from manure management systems. The captured methane is an on-farm energy resource that can offset energy costs and increase bottom-line profits. Using methane-recovery systems, it is technologically feasible to reduce total U.S. methane emissions from livestock manure by 50 percent. Collateral benefits include reducing surface- and ground-water pollution, managing odors, and reducing fertilizer costs.

To join AgSTAR, livestock producers sign a memorandum of understanding and agree to survey their facilities to determine if a methane-recovery system would be profitable for their farm(s). If it is projected to be profitable, the producer agrees to install a methane-recovery system within three years.

To date, project installations have been slower than expected, due to delays in initiating model farms and utility industry restructuring. Installations are increasing, however, due to industry emphasis on odor control and other factors.

Achievements

- AgSTAR has more than 40 partners, representing more than 400 farms. The program also has 50 Allies, representing system and equipment manufacturers, educational institutions, state and local governments, and others.
- EPA has issued the *AgSTAR Handbook*, a comprehensive methane-recovery handbook and reference guide organized for specific livestock-rearing methods and manure management strategies.
- EPA has released FarmWare version 1.0, the AgSTAR decision-support software, which allows U.S. dairy and pork producers to conduct comparative technical and economic assessments of their facilities.
- EPA has initiated projects at model farm sites in key methane areas across the country. These model farms are demonstrating the successes of today's methane-recovery technology and the potential to recover methane at a profit. These farms also serve as educational facilities for Partners, Allies, and others interested in considering methane-recovery systems.
- USDA and EPA have jointly developed three interim standards related to biogas generation, capture, and utilization—Covered Anaerobic Lagoon, Plug Flow Digester, and Complete Mix Digester—which allow AgSTAR partners to participate in cost-share programs, such as EQP.
- USDA and EPA have jointly funded an engineering position, located in Raleigh, North Carolina, to serve as a regional specialist in environmental engineering and biogas recovery.

Contacts: *Kurt Roos, EPA, Atmospheric Pollution Prevention Division,* 202-233-9041, *Barry Kintzer, USDA-NRCS, Conservation Engineering Division,* 202-720-4485.

Ruminant Livestock Efficiency Program

(Climate Plan Action 39)

In the year 2010, the Ruminant Livestock Efficiency Program is expected to generate:

- **Methane reductions of 20 billion cubic feet**
- **Carbon-equivalent savings of 2.2 MMT**

This collaborative effort between USDA and EPA aims to reduce methane emissions resulting from the dairy and beef industries, which are responsible for more than 30 MMTCE of methane emissions annually. Methane is produced as part of a ruminant animal's normal digestive process, known as "enteric fermentation." Because the methane produced is actually wasted carbon from the feed, the amount of methane relative to the amount of beef or milk produced is a reliable indicator of inefficiency of animal production.

This program encourages livestock producers to improve the efficiency of their animals and reduce methane emissions by improving grazing management, providing strategic feed supplementation, improving feed efficiency through the use of production-enhancing agents, improving genetic characteristics, improving reproduction, and controlling diseases. The program also builds on existing efforts to remove market barriers and to create incentives for increased production of lower-fat milk and meat products. Because fat production is energy-intensive, producing lower-fat products requires less feed per unit of product and results in less methane production.

Achievements

- In Utah and Washington State, regional projects were launched to study how improved livestock management practices reduce methane emissions from cattle. The information gathered by the collaborating universities is being transferred to livestock producers through local extension services.
- The Ruminant Livestock Efficiency Program has enabled USDA's National Resource and Conservation Service (NRCS) to expand upon its education and technical assistance activities in 10 states helping livestock producers improve grazing management and livestock production. Efforts include workshops, field tours, video programs, and distribution of published material.
- In collaboration with universities in Tennessee, Georgia, and Louisiana, a regional project has been launched for the southeastern United States, which focuses on improving efficiency of production on cow/calf operations. Plans were developed to study improved practices, mainly in the areas of grazing and forage management, and the effect they have on methane emissions and productivity. NRCS will use the information in technology-transfer programs. As part of this effort, "model farms" are being established in 10 states and Puerto Rico to demonstrate to producers that improved practices can be profitable and good for the environment.

Contacts: *Mark Orlic, EPA, Atmospheric Pollution Prevention Division, 202-233-9043, Steve Carmichael, USDA-NRCS/EPA Liaison, 404-562-9374*

Significant New Alternatives Program

(Climate Plan Action 40)

In the year 2010, Action 40 is expected to generate:

- Carbon-equivalent savings of 23.1 MMT

Perfluorocompounds (PFCs) and hydrofluorocarbons (HFCs) are among the most potent greenhouse gases. In addition to being characterized by high global warming potentials (GWPs), most PFCs and HFCs have extremely long atmospheric lifetimes, which means even small emissions will contribute to the cumulative atmospheric burden and will persist for up to thousands of years.

Emissions of PFCs and HFCs in this initiative fall into two categories: release from use as alternatives for ozone-depleting substances, and discharge from industrial processes. This action intends to reduce emissions of high-GWP gases by a regulatory pathway to restrict the use and emission of chemicals under the Significant New Alternative Policy (SNAP), authorized under Section 612 of the Clean Air Act.

Section 612 permits the control of uses for high-GWP gases if other alternatives to ozone-depleting substances exist and pose less risk to human health and the environment. Regulatory actions are also developed as part of the SNAP, and environmental stewardship activities have been designed to control industrial releases.

Achievements

- SNAP has promulgated four rules listing acceptable and unacceptable substitutes for ozone-depleting substances. Through these rules, EPA has restricted the use of substances by listing chemicals subject to Narrowed Use Limits. SNAP also has banned the use of some substances because of their high GWP properties (e.g., SF_6 is an unacceptable substitute for aerosol propellants due to its very high GWP and the existence of other compressed gases that perform equally well).

Contact: *Reynaldo Forte, EPA, Stratospheric Protection Division,* 202-233-9134

Expansion to CCAP Action 40: Environmental Stewardship Initiative

(New Climate Plan Action)

In the year 2010, this initiative is anticipated to generate:

- Carbon-equivalent savings of 10.0 MMT

This action expands ongoing work begun as part of the environmental stewardship activities under Action 40 of the Climate Change Action Plan. Environmental stewardship activities have been designed to control industrial emissions of perfluorocarbons (PFCs) and hydrofluorocarbons (HFCs). Among the most potent greenhouse gases, most PFCs and HFCs are characterized by high global warming potentials (GWPs) and extremely long atmospheric lifetimes. A high GWP implies that discrete emission of the gas can be up to several thousand times more potent than an equivalent quantity of carbon dioxide. Further, long atmospheric lifetimes for the gases mean that even small emissions will contribute to the cumulative atmospheric burden and persist for up to thousands of years.

PFCs and HFCs are intentionally used in the following three industries (1) semiconductor production (SF_6, CF_4, C_2F_6, C_3F_8, NF_3, and CHF_3); (2) electrical power systems (SF_6); and (3) magnesium casting (SF_6). Use and emissions of PFCs by the semiconductor industry is expected to increase by 2000 due to growing use in production and demand for the microchip. The most potent greenhouse gas is SF_6, with a GWP of 23,900 and an atmospheric lifetime of 3,200 years It is used by all three industries Atmospheric concentrations of SF_6 are increasing at an estimated annual rate of 7–8 percent. Production rates for some of the PFCs are expected to grow

Most emission reductions for these industries are believed to be possible through environmentally protective and cost-effective means. In all cases, the principles of pollution prevention are under consideration for reducing emissions EPA has initiated a cooperative reduction effort with the semiconductor industry and has begun discussions with the electrical and magnesium industries

The semiconductor industry, through efforts of the Semiconductor Industry Association and its member companies, has worked with EPA to develop an agreement to endeavor to reduce emissions of PFCs Eighteen individual companies have signed the memorandum of understanding with EPA, which has already received preliminary reports of successful attempts to reduce emissions In the meantime, the electrical and magnesium industries have both expressed a desire to discuss voluntary reduction programs with EPA

Contact: *Elizabeth Dutrow, EPA, Atmospheric Pollution Prevention Division,* 202-233-9061

Partnership With HCFC-22 Manufacturers to Eliminate HFC-23 Emissions

(Climate Plan Action 41)

In the year 2010, this initiative is expected to generate:

- **Carbon-equivalent savings of 5.0 MMT**

Chemical production of HCFC-22 results in the creation of HFC-23 (trifluoromethane) as a by-product. Vented to the atmosphere for the most part, HFC-23 is a very potent greenhouse gas, with a global warming potential of 11,700 and an atmospheric lifetime of 250 years.

This action is a voluntary environmental stewardship program designed to reduce releases of HFC-23. The U.S. producers of HCFC-22 have committed to EPA to reduce emissions of HFC-23 in the year 2000 by 5 MMTCE. Reduction opportunities will vary from company to company, but will most likely include process optimization, conversion to benign chemistries, and destruction.

Achievements

- HCFC-22 producers have completed an assessment of their 1990 HFC-23 emissions, and are continuing to report annual emissions.
- HCFC-22 producers are currently determining and implementing the most cost-effective practices for reducing HFC-23 emissions.
- In 1997, EPA and the producers coordinated to develop a set of performance-based emission measurement standards. The standards establish acceptable limits for air emissions data.

Contact: *Elizabeth Dutrow, EPA, Atmospheric Pollution Prevention Division, 202-233-9061.*

Aluminum Producer Partnership

(Climate Plan Action 42)

In the year 2010, the Voluntary Aluminum Industrial Partnership is expected to generate:

- Carbon-equivalent savings of 2.4 MMT

Carbon tetrafluoride (CF_4) and carbon hexafluoride (C_2F_6) are emitted as by-products of the primary aluminum production process. Both of these perfluorocarbons (PFCs) are potent greenhouse gases with global warming potentials of approximately 6,500 and 9,200 times that of CO_2, respectively, and lifetimes that exceed 10,000 years. Through the Voluntary Aluminum Industrial Partnership (VAIP), EPA is partnering with primary aluminum producers to reduce PFCs emissions where technically feasible and cost-effective.

PFCs are generated during anode effects, which are temporary electrochemical disruptions in the production process. When they occur, energy that would otherwise be used to make aluminum is wasted. Under VAIP, partners work toward minimizing the number and duration of anode effects without sacrificing competitiveness. Many companies have already reduced their PFC emissions substantially through relatively minor technological and operational changes, such as the use of computer monitoring, changes in raw materials feeding techniques, and employee training. EPA estimates that such changes can help to reduce PFC emissions by 30–60 percent industry-wide.

Achievements

- As of December 1995, 12 companies representing 94 percent of the U.S. primary aluminum production capacity had joined VAIP.
- VAIP has developed CF_4 and C_2F_6 gas standards (through the National Institute of Standards and Technology) and has improved the fundamental understanding of these emissions (through research conducted at the Massachusetts Institute of Technology).
- EPA has conducted measurements of CF_4 and C_2F_6 at seven smelters in conjunction with primary aluminum companies.
- In 1996, EPA co-hosted an international conference on PFC emissions from aluminum smelting attended by representatives of more than 10 countries.

Contact: *Eric Dolin, EPA, Atmospheric Pollution Prevention Division, 202-233-9044*

Accelerate Tree Planting in Nonindustrial Private Forests

(Climate Plan Action 44)

In the year 2010, trees planted through this program are expected to sequester:

- **2.2 MMT of carbon**

Through the Forest Stewardship Incentive Program, USDA's Forest Service and State Forestry agencies are providing technical assistance and up to 75 percent federal cost-sharing for the planting of additional trees on nonindustrial private lands. This program increases the uptake of carbon dioxide and storage of carbon in trees, forest soils, forest litter, and in understory plants. The goal of the program is to increase tree planting in the United States by 233,000 acres a year (10 percent) within five years and to maintain this expanded level of planting for an additional five years.

Achievements

- The USDA Forest Service has planted 135,000 acres of trees through fiscal year 1996 under the Stewardship Incentive Program.

Contact: *Robert J. Moulton, USDA Forest Service, 919-549-4032*

Climate Challenge

The Climate Challenge program is a joint, voluntary effort of DOE and the electric utility industry to reduce, avoid, or sequester greenhouse gases. Utilities identify and implement cost-effective activities that are specified in agreements between DOE and individual electric utilities. Each utility reports its results annually, consistent with the guidelines for voluntary reporting of greenhouse gas emissions developed under Section 1605(b) of the Energy Policy Act of 1992.

Actions that utilities have committed to in their agreements include: efficiency improvements in end use, distribution, transmission, and generation; increased use of energy-efficient electrotechnologies; fuel switching to lower-carbon fuels and renewables; transportation actions; forestry actions; recovery of methane from landfills and coal seams; and the use of fly ash as a Portland cement substitute. A significant effect of the Climate Challenge program is the shift in thinking of electric utility management and strategic planners to include the mitigation of greenhouse gas emissions into their corporate culture and philosophy.

Achievements

- The utility industry developed nine Climate Challenge initiatives, including: the EnviroTech Charter, with over $50 million committed to accelerate commercialization of renewable-energy technology and energy-efficient electrotechnologies; the Earth Comfort Program, to increase annual sales of energy-efficient geothermal heat pumps from 40,000 to 400,000, the Utility Forest Carbon Management Program, with over $2 million committed to funding several domestic and international projects, through the nonprofit UtiliTre Carbon Company the International Utility Efficiency Partnerships, which is currently evaluating projects in 18 countries, and the Combined Purchasing Initiative, to aggregate utility purchasing power to create a market for technologies, such as high-efficiency transformers and photovoltaics. Other initiatives include: EV America (electric vehicles), Electric End Use Efficiency Technology Initiative, Tree Power, and International Donated Equipment Initiative
- Niagara Mohawk Power Corporation exchanged 1.75 million tons of CO_2 reductions for Arizona Public Service Company's 25,000 tons of sulfur dioxide allowances. Niagara Mohawk donated the allowances to a nonprofit environmental group to be retired
- As of April 1997, 119 Participation Agreements were signed. The agreements represent 638 of the over 800 utilities that have expressed interest in the program, and 69 percent of 1990 electric generation and utility carbon emissions. These utilities' commitments are expected to reduce carbon emissions by over 44 MMTCE in the year 2000.

Contact: *Energy Efficiency and Renewable Energy Customer Service Center, 1-800-363-3732 (Domestic) or 703-287-8391 (International)*

Climate Wise

Turning Industrial Energy Efficiency and Environmental Performance into a Corporate Asset

CLIMATE WISE

In the year 2010, Climate Wise is expected to generate:

- Energy cost savings of $0.78 billion.
- Energy savings of 0.33 quads.
- Carbon-equivalent savings of 3.7 MMT.

Climate Wise is helping companies realize significant environmental and economic benefits through cost-effective industrial energy-efficiency and pollution-prevention actions. The program provides technical assistance and public recognition that result in the development and implementation of comprehensive emission-reduction action plans that achieve real results. Climate Wise's common-sense approach to pollution prevention allows companies tailor their action plans to meet the needs and opportunities of their operations.

Boiler efficiency, steam system optimization and maintenance, fuel switching and cogeneration, industrial process improvements, and air compressor system efficiency are just a few of the unique industrial actions Climate Wise companies are taking. Climate Wise partners are also encouraged to participate in other *Climate Change Action Plan* programs, such as DOE's Motor Challenge and EPA's Green Lights® programs, to ensure their plans are comprehensive.

The industrial sector accounts for about 30 percent of U.S. energy consumption and represents a broad array of emission-reduction opportunities. Climate Wise targets this important sector, requiring each Climate Wise company to develop a comprehensive action plan within six months of joining the program and report the results of its actions annually through the Section 1605(b) Voluntary Reporting System.

Achievements

- In 1996, after the program's first full year of recruitment efforts, the number of Climate Wise companies grew by more than 700 percent. Partners now number more than 250 and represent more than 7 percent of U.S. industrial energy use.
- Climate Wise partners have already committed to undertake nearly 350 pollution-prevention and energy-saving actions. In 1996, companies documented savings of more than $30 million annually. Many of the partners who joined the program in 1996 will be submitting their action plans in 1997. By the year 2000, the program expects to foster emission reductions of more than 3 million metric tons of carbon and fuel cost savings of nearly $675 million.
- The State and Local Government Allies program collectively recruited more than 100 partners in 1996. This initiative, involving ten states and six local governments in 1996, has brought the federal, state, and local governments together to deliver better services to participating companies. In addition to the tremendous outreach capability, State and Local Government Allies are creating innovative services, such as regulatory incentives and low-interest loans, to help companies achieve meaningful results

Contacts: *Amy Manheim, DOE, Office of Industrial Technologies,* 202-586-1507. *Pam Herman Milmoe, EPA, Office of Policy Planning and Evaluation,* 202-260-4407; *Climate Wise Line,* 1-800-459-*WISE* or (703) 934-3830

State and Local Climate Change Outreach Program

The Climate Change Outreach Program builds capacity to successfully reduce greenhouse gases at the state and local levels by providing needed information, tools, and infrastructure to state and local authorities. The program can be compared to a venture capital group that seeks out good investments. It helps decision makers identify and understand the impacts of climate change (e.g., public health, air quality, water resources) as well as assess and implement policies that result in the mitigation of the risks associated with climate change. Partners have a product—an action plan—that clearly shows the potential for greenhouse gas savings. Collectively, the program allows EPA to examine the opportunities for partners and extrapolate potential nationwide savings. In addition, the program has emphasized the development and analysis of innovative and integrated actions that solve multiple environmental and economic problems.

Recent changes in the program focus on outreach and communication activities to:

- Motivate officials to take action.
- Identify opportunities to contribute to the international process led by the federal government.
- Analyze the economic and environmental impacts of domestic greenhouse gas policy at the regional, state, and local levels.

Achievements

- Thirty states have completed or nearly completed state greenhouse gas inventories, enabling them to identify where their emissions are growing fastest.
- Nine states have completed and 11 others have nearly completed action plans, which have enabled them to identify numerous cost-effective measures to reduce greenhouse gas emissions
- Thirteen partners have completed demonstration greenhouse gas reduction projects or impact studies.
- State partners from Oregon and Utah are lending technical expertise to the U.S. Country Studies SNAP Program as Project Officers and Technical Experts.
- Forty-one U.S. cities are participating in the Cities for Climate Protection Campaign. Five participating cities have committed to a 20 percent emissions target and timetable, and the remaining cities are preparing local action plans. Over half of the cities are starting to implement programs that reduce greenhouse gas emissions.
- The Environmental Council of the States is engaging state environmental commissioners on climate change issues through education about the impacts of climate change on their states and the effect of changes in domestic policy that may result from the international climate negotiations.
- State- and local-targeted information is being disseminated to partners through electronic mailings, EPA's web site on global warming, workshops, and publications.

Contact: *EPA, Office of Economy and Environment,* 202-260-4314

U.S. Country Studies Program

A joint initiative of 10 U.S. government agencies, the U.S. Country Studies Program is assisting 55 developing countries and countries with economies in transition with climate change studies designed to build human and institutional capacity to address climate change. The program is also assisting 18 of these countries in using their study results to prepare national climate change action plans that will lay the foundation for their national communications required under the U.N. Framework Convention on Climate Change (UNFCCC).

The primary objectives of the U.S. CSP are:

- To enhance the abilities of countries and regions to inventory their greenhouse gas emissions, assess their vulnerabilities to climate change, and evaluate strategies for mitigating emissions and adapting to the potential impacts of climate change.
- To enable countries to establish a process for developing and implementing policies and measures to mitigate and adapt to climate change, and for reexamining these policies and measures periodically.
- To develop information that can be used to further regional, national, and international discussions of climate change issues and increase support for the FCCC.

Achievements

- Initiated a two rounds of support for national action plans to 18 countries (Bangladesh, Bolivia, Bulgaria, China, Czech Republic, Egypt, Hungary, Indonesia, Kazakstan, Mexico, Micronesia, Philippines, Russian Federation, Tanzania, Thailand, Ukraine, Uruguay, and Venezuela).
- Published several handbooks on methodologies, and three synthesis reports (emission inventories, vulnerability and adaptation assessments, and country strategies) to document the results of the studies.
- Sponsored or co-sponsored more than 30 technical workshops to share methods, results, and country strategies.
- Published handbooks and held training workshops on preparation of plans and technology assessments, and trained over 2,000 analysts in 70 countries.
- Sponsored more than 200 publications or data bases by the 55 countries.
- Developed handbooks and synthesis reports that have made important contributions to the work of the Global Environment Facility, the Intergovernmental Panel on Climate Change, and the Subsidiary Bodies to the Climate Convention, as well as other international organizations.
- Helped 55 countries complete preliminary emission inventories, vulnerability and adaptation assessments, and mitigation assessments.
- Continues to complement programs implemented by other donors (e g , the United Nations Development Program, the United Nations Environment Program, the Global Environment Facility, and individual member countries of the Organization for Economic Cooperation and Development).

Contact: *Director, U S. Country Studies Program, PO-6, 1000 Independence Ave , S W, Washington, D C. 20585, 202-586-3288; Internet site at http //www gcrio org/csp/webpage html*

The U.S. Initiative on Joint Implementation

The U.S. Initiative on Joint Implementation (USIJI) is a pilot program encouraging U.S. organizations to implement projects internationally that reduce, avoid, or sequester greenhouse gases. Since its launch in 1993, USIJI has become the largest effort worldwide to explore options for countries to jointly reduce greenhouse gases. Its international outreach activities and workshops (attended by several hundred potential participants from approximately 50 countries) have positively influenced international understanding of joint implementation and its broad acceptance by Parties to the U.N Framework Convention on Climate Change. Other countries, including Canada and Japan, have announced pilot efforts similar to USIJI.

The goals of the USIJI program are to:

- Promote technology cooperation with and sustainable development in developing and transition countries.
- Test and evaluate methods to measure, track, and verify emission reduction costs and benefits.
- Encourage private-sector investment and innovation in developing and disseminating technologies to reduce or sequester greenhouse gas emissions.
- Establish an empirical base for the formulation of international criteria for joint implementation.

Achievements

- As of December, 1996, USIJI had received 61 proposals from 26 countries for projects that were designed to reduce, avoid, or sequester greenhouse gases, using a diverse set of technologies, including renewable, fuel-switching, energy-efficiency, methane-recovery, and sustainable land-use practices. Of these, the Evaluation Panel has approved 23 projects representing innovative technologies and practices in nine countries.
- The USIJI Secretariat streamlined the project review and acceptance procedures and has published draft guidelines for preparing USIJI proposals.
- The USIJI Secretariat prepared a very detailed report to the Secretariat of the UNFCCC, which set a high standard for Annex I and non-Annex I parties under the AIJ pilot phase.
- The USIJI Secretariat established a technical assistance program to provide assistance to project participants in the areas of obtaining financing, developing monitoring and verification plans, and screening new projects for compatibility with project criteria.

Contacts: *Director, USIJI Secretariat, PO-6, 1000 Independence Ave., S.W., Washington, D.C. 20585, 202-586-3288; Information Line 202-586-3467; Fax-on-Demand: 202-260-8677; Internet web site: http://www.ji.org*

Voluntary Aluminum Industrial Partnership (VAIP)

Membership and Perfluorocarbon (PFC) Reduction Committment

VAIP Partners	1990 Primary Aluminum Production Capacity ('000 metric tons)	PFC Reduction Commitment for the year 2000 (%)
Alcan Aluminum Corp.	163.3	50%
Alumax, Inc.	600.0	31%
Aluminum Company of America	1,285.0	70%
Century Aluminum	166.0	35%
Columbia Falls Aluminum	168.0	21%
Goldendale Aluminum Co.	167.8	15%
Kaiser Aluminum & Chemical Co.	273.1	38%
Noranda, Inc.	204.1	60%
Northwest Aluminum	81.6	35%
Reynolds Metals Co.[1]	448.0	
Southwire Co.	180.0	30%
Vanalco	115.0	60%
Total for VAIP	3,851.9	
US Total	4,096.8	
VAIP Percent of Total (%)[2]	94%	

1. Reynolds is an industry leader in PFC reduction, and had prior to 1990 already achieved significant reductions. In their VAIP agreement they have committed to continue their high level of performance in this area.
2. Ormet is the only aluminum company that is not a VAIP partner. Therefore, VAIP represents about 94% of total U.S. Capacity.

<u>Aluminum Industry Partnership</u>

Q12. On page 6 of your written testimony, you state:

> ***"Aluminum Industry Partnership.*** **EPA has forged agreements with 90% of the aluminum industry to reduce their emissions of perfluorinated compounds (PFCs), which are potent greenhouse gases, by 40-60% by 2000. With key technical support from EPA, the companies are well on their way to meeting their commitments.**

Q12.1 Please identify the members of the aluminum industry participating in the Aluminum Partnership.

A12.1 See Attachment, "Voluntary Aluminum Industrial Partnership -- Membership and PFC Reduction Commitment."

Q12.2 Please document the statement that "EPA has forged agreements with 90% of the aluminum industry to reduce their emissions of perfluorinated compounds (PFCs), which are potent greenhouse gases, by 40-60% by 2000."

A12.2 See Attachment, "Voluntary Aluminum Industrial Partnership -- Membership and PFC Reduction Commitment."

Q12.3 Please provide the level of EPA funding for the Aluminum Industry Partnership in FY 1997 and FY 1998, and the amount requested for FY 1999.

A12.3 FY 1997 = $968,000
FY 1998 = $949,000
FY 1999 = not a line item

In the FY 1999 budget proposal, the Voluntary Aluminum Industrial Partnership is one component of the "Industry Initiatives" line item (see response to Question 29).

Q12.4 Please identify all recipients of the funds--by fiscal year and by amount for each recipient--identified in the response to question 12.3 above.12.2 See attachment, "Voluntary Aluminum Industrial Partnership -- Membership and PFC Reduction Commitment."

A12.4 EPA interprets this question to be based on the misconception that EPA provides financial assistance to partners in this program. EPA does not provide any funding to program participants. Instead, EPA uses its funding to disseminate reliable financial and technical information to program partners to assist them in making better decisions for investing their own money.

Metal Finishers Agreement

Q13. On page 6 of your written testimony, you state: "Metal Finishers Agreement. Through EPA's Common Sense Initiative, the metal finishing industry has committed to improving energy efficiency by 25% by the year 2002, while reducing other toxic chemicals."

Q13.1 Please identify the members of the metal finishing industry participating in the Metal Finishers Agreement.

A13.1 The Metal Finishing Strategic Goals Program (the "Agreement") was developed as part of the multi-stakeholder process of EPA's Common Sense Initiative. Many individuals from a wide variety of constituent groups B the metal finishing industry, metal finishing suppliers, state and local governments, organized labor, environmental and community groups B provided input in that process. The primary industry representatives in the process served as members of the Metal Finishing Subcommittee, the steering group for this CSI sector. These individuals endorsed the Goals Program as official representatives of the major national trade associations and constituent groups of the metal finishing industry. Their names and affiliations are listed below:

B.J. Mason, President, Mid-Atlantic Finishing, Inc.; past President of the American Electroplaters and Surface Finishers Society (AESF)

David Marsh, CEO, Marsh Plating Corporation; past President of the National Association of Metal Finishers (NAMF)

William Saas, President, Taskem, Inc.; representative of the Metal Finishing Suppliers Association (MFSA)

Robert McBride, President, A.C. Plating, Inc.; current President of NAMF

John Cullen, Director of Environmental Affairs, Masco Corp.; represents large "captive" metal finishing operations (metal finishing within manufacturing plants)

Robert Chatel, President, The Robbins Company; represents small "captive" metal finishing operations.

Q13.2 Please document the statement that "through EPA's Common Sense Initiative, the metal finishing industry has committed to improving energy efficiency by 25% by the year 2002, while reducing other toxic chemicals."

A13.2 The Metal Finishing Strategic Goals Program includes a goal of "25% reduction in facility-wide energy use" (by 2002, from 1992 levels). This goal is one of a number of voluntary, facility-based performance targets for reduced toxic emissions, improved resource efficiency, and reduced compliance costs for metal finishing companies. These performance targets are complemented by a broad set of action commitments by EPA, the industry, and other stakeholders, to provide tools and remove barriers for facilities to achieve the goals.

This entire, comprehensive Goals Program was formally endorsed by the members of the CSI Metal Finishing Subcommittee, the multi-stakeholder steering group for the sector, on December 16, 1997. By signing the Goals Program document, the industry representatives on the Metal Finishing Subcommittee signified their approval of all of the performance goals. They also committed the three major national trade associations to promote broad facility sign-up for the program and to assist participating facilities to achieve the performance goals. In so doing, they committed their industry to make a good faith effort to pursue energy efficiency and reduce toxic emissions.

Q13.3 Please provide the level of EPA funding supporting this agreement in FY 1997 and FY 1998, and the amount requested for FY 1999.

A13.3 Many activities of EPA programs and other stakeholder groups provide some form of support for the Strategic Goals Program. Since 1995, the CSI Metal Finishing Subcommittee has endorsed fourteen projects, all of which make at least an indirect contribution to the development and implementation of the Goals Program. However, certain activities provide direct support to the Program, and the funding figures for these activities are provided below:

FY 1997 = $535K
FY 1998 = $783K
FY 1999 = not a line item

Q13.4 Please identify all recipients of the funds by fiscal year and by amount for each recipient B identified in the response to question 13.3 above.

A13.4 EPA interprets this question to be based on the misconception that EPA provides financial assistance to partners in this program. EPA does not provide any funding to program participants. Instead, EPA uses its funding to disseminate reliable financial and technical information to program partners to assist them in making better decisions for investing their own money. With improved information through voluntary partnerships, companies are able to make investments that simultaneously reduce greenhouse gas emissions and reduce energy bills.

Green Lights and Energy Star Buildings

Q14. On page 6 of your written testimony, you state:

***"Green Lights and Energy Star Buildings. U.S.* companies and organizations joined EPA's Green Lights and ENERGY STAR Buildings Programs, they could reduce the carbon dioxide emissions due to the energy used in commercial buildings by 35 percent and reduce commercial buildings' energy bills by $25 billion per year."**

Q14.1 Please identify the participants of EPA's Green Lights and ENERGY STAR Buildings Programs.

A14.1 See attachment, "Participants in EPA's Green Lights and Energy Star Buildings Program"

EPA ENERGY STAR BUILDINGS® & GREEN LIGHTS®
Participant List

March 2, 1998

Total Green Lights Participants (2,424)
Green Lights Partners (1,561)
Green Lights Allies (583)
Green Lights Endorsers (301)
Total Energy Star Buildings Participants (489)
Energy Star Buildings Partners (277)
Energy Star Buildings Allies (161) 40009
Energy Star Buildings Endorsers (56)

Energy Star Buildings and Green Lights Participants

U.S. Environmental Protection Agency
Biweekly List - March 2, 1998

Partners (1,322 total)
Parent Organizations:

*3COM
3M
A & C Enercom
Great Atlantic & Pacific Tea Company
A B Emblem
AES Corporation 🎓
ALCOA ★
AMP Incorporated
ANA Hotels USA Inc
AT Cross Company
Abbott Laboratories 🎓
Academy School District 20
Adat Shalom Congregation 🎓
Adelphi University
Advantica Restaurant Group, Inc.
Advo, Inc.
Affiliated Computer Services Inc.
Air Products & Chemicals, Inc.
Alamance-Burlington School System
Alamo Community College District
Albany Medical Center Hospital 🎓
Albert Einstein Medical Center
Albertson's, Inc.
Albuquerque Technical and Vocational Institute
Alexandria City Public Schools 🎓
All City Management
Allegan General Hospital
Allegheny Regional Hospital 🎓
Allegheny University Hospitals-East Falls
Allegheny University Medical Centers-Allegheny Valley
Allen Memorial Hospital (UT)
Allen Publishing
Allergan
Alliance for Affordable Energy 🎓
Alliance to Save Energy 🎓
Alpine Inn Bed & Breakfast
Alta Bates Medical Center - Ashby Camp
Altera Corporation 🎓
Altoona Hospital
Altoona School of Commerce
Amdahl Corporation
Amelia Island Plantation
American Assn for the Adv of Science
American Auto-Matrix Inc.
American Conditioned Air, Inc.
American Council for an Energy Eff Econ 🎓
American Express
American Federation of Teachers
American Public Power Association 🎓
American Standard Inc ★
American Trucking Association
Ameritech Corporation
Ames Department Stores Incorporated
Ames Rubber Corporation
Amherst Hospital
Amoco ★
Amway Corporation 🎓
Anadigics Incorporated
Analytical Lighting Systems
Ann Arbor Public Schools 🎓
Anne Arundel Community College 🎓
Anne Arundel County Public Schools
Apex Trucking Company, Inc.
Applied Computer Technologies
Applied Materials, Inc.
Arizona State University at Tempe
Arlington Hospital
Arlington Public Schools
Asheville Mica Company
Ashland Oil Inc
Associated Industries of the Inland Northwest
Associated Students of UC Berkeley
Atlantic City Medical Center
Atlantic Community College at Meys Landing
Audubon Society of New Hampshire
Auraria Higher Education Center
Auten Technical Services
Auto Collision,Inc. 🎓
Automatic Data Processing Inc
Avon Products Incorporated
BIC Corporation
BJC Health System
BMC West Corporation
Babson College
Bacharach Rehabilitation Hospital 🎓
Bachman's Incorporated
Bailey Corporation 🎓
Baldor Electric Company 🎓
Bank of America 🎓
Bank of Hawaii
Bankers Insurance Group
Baptist Hospital of Nashville
Baptist Medical Center - Columbia
Baptist Memorial Hospital of Memphis
Baptist Regional Medical Center of Corbin, Kentucky
Barr Laboratories 🎓
Barry University 🎓
Bass Pro Shops
Bausch & Lomb
Baxter Healthcare Corp ★
Baylor College of Dentistry 🎓
Bayonne Hospital 🎓
Bear Stearns Companies, Inc.
Beaver College
Beaver Valley Hospital
Bechtel Group, Inc. ★
Beckwith Electric Company, Inc 🎓
Becton Dickinson and Company
Bed Bath & Beyond
Bell Atlantic ★
BellSouth Cellular Corporation
BellSouth Corporation 🎓
Belmont University 🎓
Bennardi and Associates
Bentley College
Bertie County Schools
Beth Israel Deaconess Medical Center
BetzDearborn Corporate Headquarters
Bigfork School District 38
Black Dome Mountain Shop, Inc.
Blockbuster Entertainment Corporation
Blue Cross & Blue Shield Mutual of Ohio ★
Bluffton College 🎓
Boatmen's National Bank of Saint Louis
Boeing

* Denotes New Participant Since February 16 1998
🎓 Green Lights Alumnus -- completed the Green Lights Program
★ Green Lights Honorable Mention -- upgraded at least 50% of eligible square footage or at least 1 million square feet
Bold Lettering Denotes Energy Star Buildings Participant
Italic Lettering Denotes Energy Star Small Business Participant

Bon Wit Plaze - Unit Owner's Association
Boswell Engineering
Boulder Community Hospital
Boulder Valley Public School District
Bradytrane Service
Brandeis University
Breckenridge School District R1
Brevard Community College
Brevard County School System
Bristol Hotel Management Corporation
Brooklyn Union Gas Co.
Brookshire Hotel
Broward Community College
Brown University
Browning-Ferris Industries
Buckeye Local Schools
Bucknell University
Buffalo School District RE-4
Buffalo State College
Burger King Corporation
Burkburnett Independent School District
Burke Associates Incorporated
Burlington Public School
Burrito Brothers
Butte College at Oroville
CF Industries, Inc.
CMAC of America Incorporated
COMPAQ Computer Corporation
CTEC Corporation
CTSI Corporation
California State Automobile Association
California Steel Industries, Inc.
Camp Dresser & McKee, Inc.
Cap and Seal Company
Cape Canaveral Marine Services, Inc.
Cardolite Corporation
CareerTrack
Carl's Jr. Restaurants
Carnegie Mellon University
Carondelet St. Joseph's Hospital
Carondelet St. Mary's Hospital
Carr Realty Corporation
Carrier Corporation North America
Carson Valley School
The Carter Center, Inc.
Carter and Burgess Incorporated
Casey's General Stores, Inc.
Catalyst Financial Group
The Catholic University of America
Catonsville Community College
Celeste Industries Corporation
Centerplex, Seattle
Centinela Hospital Medical Center
Centocor, Inc.
Central Carolina Bank ★
Central Consolidated School District #22
Central Florida Community College
Cerestar USA, Inc.
Chabot Community College
Charming Shoppes, Inc ★
Chartiers Valley School District
The Chase Manhattan Bank
Cherry Hill Board of Education
Chesapeake Bay Foundation
Chestnut Hill Hospital
Chevron ★
Chicago Botanic Garden
Chicopee Public School District
Children's Hospital/Ctr for Reconstrctve Surg
Children's World Learning Centers
Cibola County Schools
Cincinnati Public Schools
Cincinnati State Technical and Community College
The Citadel - The Military College of South Carolina
Citicorp/Citibank ★
Citizens Bank of Maryland
Citizen's Photo
City University of New York
City of Hope National Medical Center
Clark Atlanta University
Clark County School District
Claywest House, Inc.
Cleveland State University
Clovis Community College
Clovis School District
Club Corporation, International
Clyde L. Choate Mental Health Center
Coahoma Community College
Cochran Sparkle Market
College of DuPage
College of Saint Rose
College of the Mainland
College of the Redwoods
Colliers Turley Martin, Kansas City
Colonial School District
Colorado State University System Office
Columbia County School District, Florida
Columbia/HCA Healthcare Corp
Columbia University
Columbus Public Schools
ComPonX, Inc.
Comal Independent School District
Comerica Incorporated
Community College of Philadelphia
Community Consolidated School District #62
Community Hospital-Anderson/Madison Co.
Community Medical Center
Connecticut College
Connecticut Mutual Life Insurance Home Office
Connetquot Central School District
Continental Airlines, Inc.
Contra Costa Community College District
Control Solutions Incorporated
Cookson Fibers
Cooper Industries
The Corcoran Gallery and School of Art
CoreStates Financial Corporation
Cork Enterprises, Inc.
Corpus Christi Independent School District
Coshocton County Memorial Hospital
Cosmair, Inc. ★
Costco Companies, Inc.
Cottage Hospital
Countrymark Cooperative
Craig Hospital
Crestar
Crown Cork and Seal Pulaski Park Plant
Cubic Defense Systems
Cumberland County Schools
DMB Associates
Dallas Independent School District
Danaher Corporation
Darling Store Fixtures
Data General Corporation
Davenport Community School District
David Lipscomb University
Days Inn Penn State
Dayton Board of Education
Daytona Beach Community College
DeKalb County Board of Education

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Italic Lettering Denotes Energy Star Small Business Participant

DePauw University
Deaconess Hospital/Cincinnati OH
Decorah Public Library
Defiance City Schools
***Delaware State University**
Delaware Valley Utility Advisors
Dell Computer Corporation
Deluxe Corporation
Denison University
Deramus Education Pavilion
Detroit-Macomb Hospital Corporation
The Dexter Corporation
Diamond Foods Inc.
Diebold, Inc.
Digital Equipment Corporation
Doctors Hospital of Jefferson
Doctors Hospital, Massillon
Dolco Packaging Corporation
Dolphin Blue, Inc.
Donaldson Company, Inc.
Downtown Plaza Towers
Drexel University
Drexler Technology Corporation
Dudley Street Neighborhood Initiative
Duke University
Duquesne University
Dura Pharmaceuticals
Duracell ★
Dynatron Bondo
EMR
ER Carpenter Corporation, Inc.
Eanes Independent School District
Earlham College
Earth Savers, LLC
East Cleveland City School District
East Maine School District #63
Eastalco Aluminum Company
Eastern Bank Corporation
Eastern Illinois University
Eastern Slope Inn Resort
Eaton Corporation ★
Edmunds Gages
Eisenhower Medical Center
El Paso County Community College District
Electric Power Research Institute
The Electrical Assn of Philadelphia
Eli Lilly & Company
Elizabethtown College
Elkhart General Hospital ★
Elks Club of State College
Embarcadero Center
Embassy of the Netherlands
EnerSource Capital
Energy Capital Partners/MA
Energy Simulation Specialists
Enron Property Company
Environmental Defense Fund
Environmental Fund for Indiana
Environmental Law Institute
Ephrata Community Hospital
Episcopal Diocese of Massachusetts
Episcopal Hospital
Equitable Resources, Inc.
Erickson's Diversified Corporation
Esprit
Eveready Battery Company, Inc.
Expense Audit & Consulting Company, Inc.
F&W Publications, Inc.
Facility Management Consultants
Fairfax Memorial Hospital
Fairfield City School District
Fairfield Medical Center
Fairmont Minerals, Ltd.
Fairmont School District
Fairmount East Apartments
Fairview Southdale Hospital, Minneapolis
Farmers & Merchants Trust Company
Fauquier Hospital, Warrenton
Fayette County School District
Federal National Mortgage Assn (FANNIE MAE)
Felton Brush, Inc.
Fina Incorporated
First Data Corporation
First Hawaiian Inc.
First International Asset Management
First Maryland Bancorp
First Security Corporation
First Union National Bank
Firstar Bank Madison NA
Fisher-Titus Medical Center
Fisk University
Flamingo Hilton ★
Flower Hospital
Fontana Unified School District
Fordham Preparatory School
Forsyth County Environmental Affairs Departments
Foxwoods Resort and Casino
Frederick Memorial Hospital
Frederick Veterinary Center
Freeman Spogli & Company
Fudpucker's of Fort Walton Beach, Inc.
G Pierce Wood Memorial Hospital
G.D. Searle Company
GDE Systems, Inc.
GEC Marconi Electronics Systems Corp
GGS Information Services
GM Popkey Company, Inc.
Gallipolis City School District
Garden Fresh Restaurant Corporation
Garden State Tanning
Gateway 2000
Geisinger Medical Center
The George Washington University
Georgetown University
Georgia Institute of Technology
Georgia State University
Gilbert Engineering
The Gillette Company ★
Godfrey Realty Company, Inc.
Gold Trail School District
Goleta Valley Cottage Hospital
Good Samaritan Hospital (Oregon)
Good Shepherd Medical Center
Goodman, Segar, Hogan, Hoffler
Goodwill Industries
The Goodyear Tire & Rubber Company ★
Gordon Food Service
The Graduate Hospital
Grand Court
Grant County Public Schools
Green Mountain College
Greene County Memorial Hospital
Greenwich Chrysler
Gwynedd-Mercy College
HB Fuller Company ★
HON Industries Inc.
Hackensack Medical Center
Halliburton Company
Hallmark Cards Incorporated
Hancock Fabrics, Inc.

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Italic Lettering Denotes Energy Star Small Business Participant

Hanover General Hospital
Harbor Hospital Center ☛
Harborview Medical Center
Harley-Davidson, Inc. ☛
Harrah's Las Vegas
Harriman City School District
Harris Bankcorp Incorporated
Harris Corporation ★
Harrisburg Area Community College
Hartsfield Atlanta International Airport
The Harvard Crimson
Harvard Medical School
Hasbro Industries ☛
Hawaii Convention Center
Haworth Inc
Hayward Unified School District
Haywood County Hospital ☛
Haywood Vocational Opportunities
Healthsource Inc
Hebrew Home & Hospital
Hebron City School District 7
Helene Curtis
Henry Medical Center ☛
Heritage Place
Heritage Pointe ☛
Herman Miller, Inc.
Hewlett-Packard Co ★
Highland Plaza Office Building
Highlands Regional Medical Center
Hilton Hotels Corporation
Hitech Corporation
Hoechst Celanese ★
Hoffmann-La Roche Inc.
Hofstra University ☛
Hogan & Hartson ☛
Holiday Inns, Inc.
Holy Cross Hospital of Silver Spring ☛
Holy Family Convent/Infirmary ☛
Holzer Medical Center
The Homasote Company ☛
The Home Depot ☛
Home Savings of America ☛
Honeywell, Inc. (Bloomington) ☛
Hood College
Horton Memorial Hospital ★
Houston Independent School District
Huls America Incorporated
The Humane Society of the United States
Humble Independent School District
Huntington Memorial Hospital/CA ☛
Huntington Memorial Hospital/IN ☛
Huntsville City Schools
Hyatt Corporation
ICF Incorporated ☛
IN-N-OUT Burger, A California Corporation
INOVA Health Systems
ITT Hartford Group, Incorporated
ITT Industries, Incorporated
Illinois Agricultural Association ☛
Illinois State University
The Immune Response Corporation ☛
Independence School District ☛
Independent School District 625
Indiana State University ☛
Indiana University Hospital
Inn America Hospitality, Inc.
Institute of Electrical and Electronic Engineers ☛
Interface, Inc.
Interface Research Corporation
Intergraph Corporation
Intermountain Health Care ☛
International Institute for Energy Conservation ☛
International Paper - Pine Bluff Mill
International Technology Corporation ☛
Irvine Unified School District
Irwin Seating Company ☛
Izaak Walton League ☛
JC Blair Memorial Hospital ☛
JC Penney Company, Inc.
J.C. Proctor Endowment Home
JE Seagram Corporation
JFMC Facilities Corporation
JM Smucker Company
JPS International Company
Jay Peak Ski And Summer Resort
Jefferson County Public Schools, Lakewood
Jersey Shore Medical Center
The Jewish Home for the Elderly ★
Jimmy Swaggart Ministries
John Buck Company
John Muir Medical Center ☛
Johns Hopkins/SAIS ☛
Johnson & Johnson ☛
Johnson Bible College Academic Facilities
Johnson Controls World Services, Inc. ☛
Johnson & Higgins
Joseph V. Arno
K & B Environmental
K & B Incorporated
Kabelin Commercial Supply
Kaiser Foundation Healthcare Incorporated
Kalispell Hospital
Kanawha County Schools
Kansas City, Kansas Public Schools
Kenetech Windpower ☛
Kennametal Inc.
Kennesaw State University
Kent County Public Schools
Kent State University Main Campus
Kent and Queen Anne's Hospital
Kern High School District
Kerr-McGee Corp
Keycorp ★
Kindercare Learning Centers ☛
Kingman Regional Medical Center ☛
Kinko's Service Corporation ☛
Kirby Foods
Kmart Corporation
Kolar Management Inc ☛
Koury Corporation
LL Bean Inc ☛
LSI Logic Corp.
La Porte Hospital ☛
La Quinta Inns Inc.
La-Z-Boy Chair Company
Laguna Honda Hospital & Rehab Center
Lake Tahoe Community College
Lakes Region General Hospital ☛
Landis and Staefa, Incorporated ☛
Lands' End, Inc.
Larry's Markets, Incorporated
Lee E. Stine, Inc.
Lee Memorial Health System
Lesley College
Lewis Palmer School District
Liberty Hospital ☛
Lifespan
Lima Memorial Hospital ☛
Littlefield Real Estate Company ☛
Livermore Valley Joint Unified School District

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Lockheed Martin Corporation
Lodi Unified School District 🎓
London Calling
Long Beach Marriott Hotel
Long Beach Memorial Medical Center 🎓
Longs Drug Stores ★
Los Angeles Jewish Homes for the Aging 🎓
Los Angeles Unified School District
Los Angeles Valley College
Los Rios Community College District
Louis Dreyfus Property Group 🎓
Louisville City Schools
Louisville Resource Conservation Council 🎓
Louisville & Jefferson Metro Sewer Dist 🎓
Lowe's Companies, Inc. 🎓
Lutheran Homes of Oshkosh 🎓
Lutheran Medical Center of New York
Lyondell Petrochemical 🎓
MBNA Corporation 🎓
MacFrugal's Bargains Close-Outs Inc.
Macomb Intermediate School District
Magellan Health Services
Magnetek, Inc.
Maine College of Art
Malden Mills
Manko, Gold & Katcher 🎓
Mannington Mills, Incorporated
Mansfield & Green 🎓
Marian Community Hospital
Manen Manor, Inc.
Maricopa Community Colleges
Marine Midland Bank
Marion County School District of Tennessee
Marion County Schools
Marion General Hospital
Marriott Corporation ★
Marsh Company
Marshalltown Community Schools
Martin County School District
Mary Kay, Inc.
Mary Washington Hospital 🎓
Maryland Brush Company 🎓
Maryland Historical Society
Maryland Science Center 🎓
Maryville College 🎓
Masonic Geriatric Healthcare Center
Massachusetts Institute of Technology 🎓
Mattel Inc.
Maysteel Corporation
McDonald's Corporation
McKeesport Hospital ★
McNeil Real Estate Management ★
McPherson Hospital
Meadowcreek 🎓
Mecklenburg County Public Schools 🎓
Medcenter 🎓
Medeva Pharmaceuticals Manufacturing Inc.
Media On 🎓
Medical Center of Central Georgia
Medical College of Georgia
Medina Valley Independent School District 🎓
Melrose-Wakefield Hospital Association
The Melville Corporation 🎓
Memorial Hospital, **Chattanooga**
Memorial Hospital at Gulfport
Memorial Hospital of Lafayette County 🎓
Memorial Hospital of Union County
Memorial Hospital of Washington County
Mendocino Brewing Company 🎓
Menlove Dodge Toyota
Mercantile Stores Company Incorporated
Mercy Fitzgerald Medical Center (PA) 🎓
Mercy Health Center
Mercy Hospital (OH)
Mercy Hospital (Wilkes-Barre)
Mercy Hospital of Pittsburgh 🎓
Mercy Medical Center (MD)
Mercy Memorial Hospital (MI)
Meritcare Health System
Methodist Hospital (IN)
Methodist Hospital (PA) 🎓
Methodist Hospital of Southern California 🎓
Methodist Hospitals of Memphis 🎓
Metropolitan Atlanta Rapid Transit Auth
Metropolitan Transit Authority of Houston
Metropolitan Water Rec Dist/Gr Chicago
Miami University of Ohio
Michigan State University
Microsoft Corporation
Mid Michigan Community College
Middlebury College
Milford Memorial Hospital
Millipore Corporation 🎓
Milpitas Unified School District 🎓
Milwaukee Area Technical College
Milwaukee Insurance
Milwaukee Public Schools 🎓
Miners Memorial Medical Center 🎓
Minneapolis Pub Schools & Spec Dist #1 🎓
Minnesota Mutual Life Insurance Company 🎓
Mira Costa College
Mitre Corporation
Mobil Corp
Mobile Tool 🎓
Monadnock Community Hospital
Monsanto Company
Montclair State University
Montgomery College Central Administration
Morehead State University
Morrison Knudsen Corporation
Morristown Memorial Hospital
Moses Taylor Hospital 🎓
Moss Rehabilitation Hospital
Motorola Incorporated
Mt. Bachelor Ski & Summer Resort
Mount Sinai Hospital
Mt. Carmel Health Systems
Multek
Multi-Service,Inc.
Munroe Regional Medical Center 🎓
Murphy Oil Corporation
Murray City Schools District 🎓
NYNEX Corporation ★
Natick Village Condominiums Association 🎓
National Ctr for Manufacturing Sciences 🎓
National Jewish Hospital 🎓
National Westminister Bancorp Inc ★
National Wildlife Federation
Nationwide Mutual Insurance Company, Inc.
Natural Environments, Inc. 🎓
Natural Resources Defense Council 🎓
The Nature Conservancy
The Navajo Nation
Neighborhood Service Center 🎓
Nestle USA
New Hampshire Hospital Association 🎓
New Hampshire School Admin Unit #51 🎓
New Jersey Transit
New Marine Company L.P. 🎓
New Riegel Schools 🎓

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New York Life Insurance & Annuity Corp.
New York Marriott Marquis
Newark Board of Education
Newpark Shipbuilding & Repair, Inc.
Newport Hospital (RI)
Nike, Inc. ★
Norristown Area School District
North Arundel Hospital
North Carolina Alternative Energy Corp
North Carolina Outward Bound School
North Carolina State University
North Jersey District Water Supply Commission
North Little Rock School District
North Ottawa Community Hospital
North Philadelphia Health System
North Shore Medical Center, Inc.
Northeastern University
Northern Arizona University
Northern Illinois Medical Center
Northern VA Regional Park Authority
Northland College
Northridge Associates, L.L.C.
Northrop Grumman Corporation
Northwest Community Healthcare
Northwest Covenant Medical Center
Northwest Georgia Regional Hospital
Northwest Hospital Center
Norwich University
Nuestra Comunidad Development Corporation
OECO Corporation
O'Mara Industries
Oak Grove School District
Oak Hills Local School District
Oak Park Unified School District
Ocean County College
The Ocean County Utilities Authority
Oglethorpe University, Atlanta
Ohio State University, Columbus
Okeechobee School Board
Oklahoma City Public Schools
Old Kent Financial Corporation
The Old North Church
Olympia Community Unit School District 16
One Enterprise Center
One Marconi Place, Inc.
One Town Center Associates
Orange County, Florida
Orleans Parish School Board
Oryx Energy Company Inc.
Osceola County School District
Outrigger Hotels Hawaii
Owens Construction
Oxford Properties Florida
PHH Corporation
Pace University
PaineWebber Incorporated
Pajaro Valley Unified School District
Palm Beach County School Board
PanEnergy
Panarem, Inc.
Park Ridge Hospital
Parley Redd Mercantile
Pasadena City College
Patagonia
Pathmark Stores, Inc.
Pattie A Clay Hospital
Pearl Pressman Liberty Communications Grp
Peninsula Conservation Center Foundation
Pennsylvania Blue Shield
Pennsylvania Hospital
Pennzoil Company
Pequod Associates
Peralta Community College District
Petco Animal Supplies
Phar Mor Incorporated
Phil Smidt & Son, Inc.
Philadelphia Newspapers Inc.
Philips Electronics North America Corp.
Phillips Petroleum
Phoenix Earth Food Cooperative
Phoenix Home Life Mutual Insurance Co. ★
Phoenixville Hospital, Pennsylvania
Physicians Memorial Hospital
Pima Community College
Pine Run Community
Pitney Bowes, Inc.
Planned Parenthood of SC Michigan
Platte Community School District 11-3
Pohanka Automotive Group
Polaroid Corp.
Polestar Plastics
Polk Community College
Pollution Prevention International
Pomona Valley Hospital Medical Center
Port Authority of NY/NJ; Bus Terminal
Port Authority of NY/NJ; World Trade Center
Port of Seattle, Aviation Division
Portland Public Schools
Pottsboro Independent School District
Poway Unified School District
Powell Electronics
Presbyterian Healthcare System
Prescott Aerospace, Inc.
Princeton Community Hospital
Princeton University
Principal Financial Group
Professional Mechanical Systems, Inc.
Providence Hospital, Washington, D.C.
Providence Yakima Medical Center
Provident Life & Accident Insurance Co.
Prudential Insurance Company of America, Inc.
Public Citizen
Puerto Rico Ports Authority
QDC Property Management, Inc.
Quad Graphics
Quaker State Corporation
Quakertown Community School District
Quebecor Printing Providence, Inc.
Quorum Health Group Incorporated
R.R. Donnelley and Sons Company
Radford University
Raleigh Office Building
Ralph's Grocery Company
Randolph Macon College
Ravenswood Hospital Medical Center
Raychem Corporation
Rayovac Corporation
Redlands Federal Bank ★
Reebok International Limited
Rensselaer Polytechnic Institute
Research Triangle Institute
Resources For The Future
Rexam
Rhone-Poulenc, Inc. ★
The Rice University
The Richard Stockton College of New Jersey
Richfood Holdings, Inc.
Ricoh Electronics
Riggs National Bank
Rising Sun Energy Center

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Rite Aid Corporation
Riverside Hospital
Riverside Regional Medical Center
Riverside Unified School District
Robert F. Kennedy Medical Center
Robert L. Johnson & Associates 🎓
Robert Wood Johnson University Hospital 🎓
Rochester City School District
Rochester Community School District
Rochester Institute of Technology 🎓
Rockingham Memorial Hospital
Rockwell International Corporation
Rocky Mountain Institute 🎓
Rogers Associates Architects 🎓
Roman Catholic Archbishop of Boston, a Corporation Sole
Rose Medical Center
Roseville City School District
Royal Maccabees Life Insurance Company
Roziers Mercantile Company Incorporated
Rutgers University
Rykoff-Sexton
SAIC 🎓
SC Johnson and-Son, Inc.
SCT Yarns, Inc.
Sachem Central School District
Sacred Heart Medical Center
Saddleback Valley Unified School District
Safeway Inc.
Saint Anthony's Parish
St. Charles Medical Center 🎓
St. Christopher's Hospital for Children, Philadelphia
St. Elizabeth's Health Center
St. Elizabeth's Hospital (IL)
St. Joseph Hospital (PA) 🎓
St. Joseph's Hospital (NC) 🎓
St. Joseph's Hospital
St. Joseph's Medical Center (CA) 🎓
Saint Louis Public Schools Board of Education
St. Luke's Hospital (FL) 🎓
St. Luke's Regional Medical Center (ID)
St. Mark's School 🎓
St. Mary's Hospital (IL) 🎓
St. Mary's University
St. Michael Hospital (WI)
St. Paul Fire and Marine Insurance 🎓
Saint Peter's College at Jersey City
St. Regis Mohawk Tribe
St. Thomas Hospital (TN)
Salem Community College at Carneys Point
The Salvation Army - Southern Territory
San Diego Convention Center 🎓
San Diego Model Railroad Museum 🎓
San Diego Unified School District
Sandy Spring National Bank
Santa Clarita Community College
Santa Cruz Valley Union High School Dist 🎓
Sarasota County, FL, School Board
Sarasota Memorial Hospital 🎓
Saugus Union School District 🎓
Science Museum of Minnesota 🎓
Scripps Health 🎓
Seagate Technology, Inc.
Sealed Air Corporation 🎓
Seattle Public Schools
Seattle University
Service Merchandise Company Inc
Servidyne 🎓
Seventh Generation, Inc. 🎓
Sevier County School District 🎓
Seville Apartments, LLC
Shaw's Supermarkets, Inc.
Sheldon Jackson College
Shell Oil Company 🎓
ShopKo Stores, Inc. 🎓
The Shorenstein Company
Siebe Environmental Controls, Illinois 🎓
Siemens Corporation
Siemens Stromberg Carlson
Sierra Power Group Inc. 🎓
Signet Banking Corporation
Silicon Graphics Incorporated
Sinai Hospital of Baltimore, Inc.
Sisters Of St. Francis Of Sylvania, Ohio
Skeff Distributing Company, Inc.
Sligo Adventist School 🎓
Smith Alarm Systems 🎓
Smith Club Management
Smith College
Snap-on Incorporated
Society for the Protection of NH Forests 🎓
Solberg Manufacturing, Inc.
Somerset Hills Hotel 🎓
Sony Pictures Entertainment
South Coast Air Quality Management Dist
South Hills Health System
South Jersey Hospital, Bridgeton
South Jersey Medical Center
South Pasadena Unified School District
Southeast Energy Technical Group
Southeastern University
Southern California Gas Company 🎓
Southern Nuclear Operating Company 🎓
Southface Energy Institute 🎓
Southwest Texas State University
Southwestern College 🎓
Spartan Printing Company 🎓
Special Tees, Inc.
Spectacor Management Corporation
Spir-it, Incorporated 🎓
Springfield College
Springfield Hospital
Springfield School District
Square D Company
Stafford Township Board Of Education
Stambaugh-Thompson
Standard Federal Bank
Standard Microsystems Corporation
Stanford Health Services
Stanford University Academic Facilities
Staples, Inc. 🎓
State Compensation Insurance Fund
State Farm Mutual Automobile Ins Co
State University of New York System 🎓
State Univ of New York at Stony Brook ★
Steelcase Inc ★
Stillpoint Bed & Breakfast 🎓
Stillwater Medical Center
Stone Ridge School of the Sacred Heart 🎓
Stonyfield Farm, Inc.
Storage Technology Corporation
The Store
Straub Clinic and Hospital 🎓
Student Loan Marketing Assn (SALLIE MAE)
Subway Sandwiches and Salads, Inc. 🎓
Sud Associates, PA 🎓
Summit Medical Center 🎓
Sun Company Inc.
Sun Microsystems, Incorporated
SuperValu Stores, Inc. ★
Superior Tube Company

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Susquehanna Pfaltzgraff Company
Swedish Covenant Hospital 🎓
TDIndustries
Taylor Hospital 🎓
Team Tierno Enterprises, DBA The Hanford House
Technical Resources International, Inc. (TRI)
Tenet Healthcare Corporation
Terra Resources Inc. 🎓
TerraPro Property Management Company
Texaco ★
Texas Medical Center 🎓
Texas Natural Resources Conservation Commission
Thiel College
Thomas-Fay-Custer School District
Thomas Jefferson University
Thrifty/Payless Incorporated
Tidyman's
The Timberland Company ★
Toccoa Falls College
Tonganoxie Valley Unified School District 464
Torrance Memorial Hospital 🎓
Toshiba America
Towamencin Beverage 🎓
Toy Chest-Kid's Closet
Toyota Auto Body of California, Inc.
Toyota Motor Sales USA Inc 🎓
Trade Press Publishing Corporation 🎓
Trumbull Memorial Hospital
Tucson Medical Center
Tufts University
Tulane University Medical Center
Tulsa Public Schools
Twin Lakes Regional Medical Center
Two Town Center Associates 🎓
Tyson Foods Incorporated
ULLICO 🎓
UNISYS Corporation
US Bancorp ★
US Generating Company
US West, Inc. 🎓
USF&G
Uintah Basin Medical Center 🎓
Uintah County School District 🎓
Underwriters Laboratories, Inc.
Unifirst Corp.
Unihealth America (PHR) 🎓
Unilever U.S. 🎓
Union Camp Corporation 🎓
Union College
Union of Concerned Scientists 🎓
Uniontown Hospital
United Companies Realty and Development, Inc. 🎓
United Energy of Missouri, Inc. 🎓
United Water New Jersey Inc. 🎓
Unity College 🎓
Universal Studios Florida
University Corp For Atmos Research ★
University Hospitals (Cleveland)
University of Arizona
University of California at Berkeley 🎓
University of Central Oklahoma
University of Chicago
University of Cincinnati
University of Connecticut
University of Delaware at Newark
University of Denver
University of Georgia ★
The University of Illinois at Chicago
University of Miami
University of Michigan Hospitals
University of Michigan
University of Missouri at Columbia 🎓
University of Oklahoma Norman Campus
University of Pennsylvania - Main Campus
University of Pittsburgh
University of Pittsburgh Medical Center
University of Puerto Rico
University of Redlands 🎓
University of Richmond
University of Rochester 🎓
University of San Diego 🎓
University of Scranton
University of South Carolina - Columbia
University of Southern California
University of Southern Maine
University of Virginia
University of Wyoming
University of the Arts at Philadelphia
Upper Merion Area School District
Utah State Hospital
The Valley Hospital 🎓
Valley Motors Incorporated 🎓
Van Der Horst USA ★
Vassar College
Venture Stores Inc. 🎓
Vermont Law School 🎓
Viking Freight System, Inc.
Villa View Community Hospital
Villanova University
Virginia Tech Foundation, Inc.
Volvo Cars of North America
WMX Technologies Incorporated
WNC Regional Air Pollution Control Agency
WR Grace & Company
WRC-TV
Wachovia Corp
Wake County Public School System
Wake Forest University
Wal-Mart Stores, Inc.
Walgreens Co.
Wall Technology, Incorporated 🎓
Wall & Associates
Walton Monroe Mills, Inc.
Warner-Lambert 🎓
Warren Wilson College
Warwick Condominium Association Incorporated
Waseca Independent School District 829 🎓
Washington County Hospital 🎓
Washington DC Public Schools
The Washington Times
Washington University
Waterford Mortgage Corporation 🎓
Waters Corporation 🎓
Webster University
Weirton Medical Center
Weiser Lock Company
Welborn Baptist Hospital
Wellington Sears Company
Wesleyan University of Connecticut
West Allis Memorial Hospital
West Chester University
The West Company
West Jersey Health System Inc. 🎓
Western Digital Corporation 🎓
Western Queens Community Hospital 🎓
Westin Hotels & Resorts ★
Westinghouse Electric Corporation ★
Westminster College ★
Wheaton Park District
Whirlpool 🎓

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Whitaker Newsletters, Inc. 🎓
White Castle Systems Inc 🎓
Wichita Public Schools Unified School District 259
Winslow Township School District 🎓
Winter Haven Chamber of Commerce
Witco Corporation
Woodlake Towers
Woodloch Pines
Work Stations, Inc.
World Vision 🎓
World Wildlife Fund 🎓
Worthington City School District
Worthington Industries Inc.
Wright State University
Xerox Corporation ★
YMCA at the University of Illinois, Urbana-Champaign
YMCA of Philadelphia
Yale University Arts and Sciences Campus
Yamaha Corporation of America
Yellow Freight Systems, Inc.
York Hospital of Maine 🎓
Yosemite Community College District
Zapata County Independent School District 🎓
Zoological Society of Philadelphia

Subsidiary Organizations:

AFC Enterprises, Inc. dba Churches Chicken
ALLTEL Information Services, Inc. 🎓
ANR Pipeline Company
Alaska Air Group Inc
Alliant Techsystems, Inc.
American Broadcasting Companies, Inc. 🎓
American & Efird Inc 🎓
Aristech Chemical Corp
BDM International
BP Exploration - Alaska 🎓
BP Exploration 🎓
BT Office Products International, Inc.
BellSouth Telecommunications
Belmont Center for Comprehensive Treatment
Beverly Health and Rehabilitation Services, Inc. 🎓
BioWhittaker Inc.
Bryn Mawr Hospital
Bucyrus Blades 🎓
Camac Corporation
Century I & Century II Office Buildings
Charles E. Smith Management, Inc.
Colonial Pacific Leasing 🎓
Community Medical Center, Scranton
Continental Maritime of San Diego 🎓
Countrywide Home Loans 🎓
Dean Witter Realty 🎓
Dresser Rand 🎓
E Source, Inc. 🎓
Eastern Idaho Regional Medical Center, Idaho Falls 🎓
Eckerd Corporation ★
Energy User News (Chilton Publications) 🎓
Enterprise Property Management, Inc.
Epson Portland Inc. 🎓
FHP, Inc.
First Chicago NBD ★
First Data Resources, Inc.
Forbes Regional Hospital 🎓
Foxboro Company 🎓
GPU Service Corporation 🎓
Geneva Pharmaceuticals 🎓
Harper Hospital
Harrisburg Hospital
Home Box Office ★
Horizon Air Industries, Inc.
Hughes Defense Communications
IKEA Property, Inc.
IMS America Ltd. ★
Jantzen, Inc.
Jewel Food Stores ★
John F. Kennedy School of Government at Harvard U. 🎓
Kenyon Oil Company 🎓
Lerner New York
Loews Annapolis Hotel 🎓
Luther Seminary
MGM Grand Hotel, Inc. 🎓
ML Park Place Corporation 🎓
Marathon Oil Company
Meadow Wood Hospital 🎓
Medical Area Total Energy Plant Inc of Harvard U 🎓
Mercy Hospital (Willard)
Mervyn's
Michigan Consolidated Gas Company
Midlantic Bank, N.A.
Navistar International Transportation Corporation
PACO, Wholly Owned Subsidiary of The West Co
Pacific Bell
Parkson Corporation 🎓
Powell Electrical Manufacturing Company 🎓
Preston Trucking
Queen's Medical Center
Real-Time Laboratories, Inc. 🎓
Reliance Standard Life Insurance
Saint Agnes Hospital 🎓
St. Louis Children's Hospital
Siemens Business Communication Systems Incorporated 🎓
Solar Turbines
Sony Electronics Inc.
Southern Company Services, Inc. 🎓
Spectrolab Incorporated 🎓
Sprint Southern Operations
Target Stores
Thomson Consumer Electronics, Inc.
The Toledo Hospital
USX/US Steel Group ★
United Hospital (Children's Hospital) 🎓
University of Michigan Housing Division
University of South Alabama
The University of Texas M.D. Anderson Cancer Center 🎓
Waldenbooks
Walt Disney Studios
Wastren

Divisions:

1999 Avenue of the Stars
55 Broad Street Company
ABB Instrumentation Incorporated
Allegheny University Hospitals, Bucks County
Allegheny University Hospitals, Center City
Allegheny University Hospitals, Elkins Park
Allegheny University Hospitals, Pittsburgh
AlliedSignal, Amorphous Metals
Andrew Corporation, Communication Products
Andrew Corporation, Communication Systems
Andrew Corporation, Wireless Products
Aramark, World Headquarters
Arizona Chemical, Port St. Joe, Florida
Ball Corporation, Metal Container Operations
Bone and Joint Hospital 🎓
Brown & Sharpe Manufacturing Co., Rhode Island Division
CIGNA Corporation, Corporate Real Estate Div.
Caterpillar, Inc., Headquarters
Caterpillar, Inc., TTTD

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Italic Lettering Denotes Energy Star Small Business Participant

The Coca-Cola Company (Corporate Facilities)
Community Hospital of Springfield Ohio
Cox Newspapers/Atlanta Journal and Constitution
Crown Cork and Seal Worldwide Headquarters
Dayton Hudson Corporation Department Stores Division
Delta Air Lines Headquarters
Dial Corporation, Montgomery Plant
El Dupont de Nemours and Company - DuPont Facilities Servi
East Carolina University
Florida International University
Ford Motor Company - Electronics Operations/ACO
General Motors Corp/Truck Grp & Saturn Corp
General Motors Hughes Electronics - Corp. Hdqtrs
Georgia-Pacific Center
Guy Carpenter and Company
Hazeltine Corporation
Hines Interests Ltd P'ship: Columbia Sq.
Holyoke Community College
Hughes Space and Communications Company
International Paper/Kraft Packaging Division
International Paper/Kraft Packaging Mobile Plant
International Paper - Odenton, MD Facility
International Paper/Texarkana Mill
Johns Hopkins University, Montgomery County Center
Kaiser Permanente-Hawaii Region
Kaiser Permanente-Northern California Region
Kaiser Permanente-Northwest Region
Las Positas College
Long Island University Southampton College
Louisiana-Pacific Corporation Western Division
Louisiana State U./Agricultural & Mechanical Coll
Lucky Stores Incorporated Southern Division
MCI Telecommunications Corp/Bensenville
MCI Telecommunications Corp/Downers Grove Ops
MCI Telecommunications Incorporated - Richardson Texas Fa
MCI Telecommunications Corp/Willow Springs
MacWhyte Co., Division Amsted Industries
***Massachusetts Maritime Academy**
McKeever Environmental Learning Center
Merck & Company - World Headquarters
National Broadcasting Company, Inc.
Northeastern Illinois University
Northern Illinois University
Northrop Grumman-Commercial Aircraft Division\Vought Cen
Novartis A G ★
PPG Industries, Inc./General Office
Paoli Memorial Hospital, Pennsylvania
PepsiCo. Inc.
Pfizer, Inc. (NY Headquarters Facility)
Port Authority of NY/NJ; Newark Legal Cntr.
Port Authority of NY/NJ; Port Newark/Port Elizabeth
Quebecor Printing Buffalo, Inc.
Quebecor Printing, Glen Burnie, MD
Ralston Purina Checkerboard Square Headquarters
Raytheon Systems Company, Sensors & Electronic Systems
Rhode Island Blood Center
Riviana Foods, Inc. Edison Distribution Ctr
Saint Margaret Mercy Healthcare Centers
Scientific-Atlanta Instrumentation Grp
SeaquistPerfect Dispensing - A Division of AptarGroup
Southern Illinois University at Edwardsville
Southern Oregon University
Tarleton State University
Teradyne Connection Systems, Inc.
Texfi Blends
Turner Broadcasting System, Inc.
University of Alaska, Anchorage
University of Alaska, Fairbanks
University of California at Davis
University of California at Santa Cruz
University of Florida
University of Minnesota-Twin Cities
University of Nevada at Las Vegas
University of New Orleans
University of North Carolina at Charlotte
University of South Carolina Spartanburg
University of South Florida
University of Texas Health Science Ctr/Houston
University of West Florida at Pensacola
Volt Viewtech Inc.
Walt Disney World Company
West Virginia School of Osteopathic Medicine
West Virginia University at Morgantown

Government Partners (239 total)

City of Ada, Oklahoma
Allegheny County, Pennsylvania
City of Allentown, Pennsylvania
City of Ann Arbor, Michigan
The City of Annapolis, Maryland
Anne Arundel County, Maryland
The State of Arkansas
Arlington County, Virginia
City of Atlanta, Georgia
The City of Austin, Texas
The City of Azusa, California
Baltimore County Schools, Maryland
The City of Baltimore, Maryland
Baltimore County, Maryland
The City of Berkeley, California
The City of Birmingham, Alabama
City of Boca Raton, Florida
Bonneville Power Administration
***Boston, Massachusetts, City of, The**
City of Boulder, Colorado
Boulder County, Colorado
The City of Bowling Green, Ohio
Broward County, Florida
Bucks County, Pennsylvania
California State University System
The State of California ★
City of Cambridge, Massachusetts
Cecil County, Maryland
The City of Chesapeake, Virginia
County of Chester, Pennsylvania
The Town of Cheverly, Maryland
The City of Chicago, Illinois
The City of Chula Vista, California
Cincinnati, City of
Cobb County, Georgia
Town of Conway, New Hampshire
Cook County, Illinois
Dade County, Florida
The City & County of Denver, Colorado
Douglas County, Oregon
City of Duluth, Minnesota
Environmental Protection Agency
City of Eugene Oregon
City of Falls Church, Virginia
Fauquier County, Virginia
The Town of Flemington, West Virginia
***Fort Bend, Texas, County of**
Frederick County, Maryland
Fremont Unified School District
Fulton County, Georgia
The Town of Gilbert, Arizona
The Village of Glenview Board, Illinois
The Glenview Library Board, Illinois
The Glenview Park District Board, Illinois

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Glenview (IL) School District #225
The City of Grapevine, Texas
City of Greensboro, North Carolina
Harford County, Maryland
The State of Hawaii ★
Hillsborough County, Florida
City and County of Honolulu, Hawaii
The City of Houston, Texas
Howard County, Maryland
The City of Inglewood, California
State of Iowa
City of Kansas City, Missouri
Kent County, Maryland
King County, Washington
Lee County, Florida
Leon County, Florida 🎓
The City of Little Rock, Arkansas
The City of Loma Linda, California
The City of Lompoc, California 🎓
The City of Los Angeles, California
County of Los Angeles, California
The City of Louisville, Kentucky
County of Lucas, Ohio
The State of Maine
Maricopa County, Arizona
The State of Maryland
The Commonwealth of Massachusetts ★
The City of Memphis, Tennessee
Mercer County, New Jersey
The State of Michigan
The State of Missouri
State of Montana
Montgomery County, Maryland 🎓
City of Mount Rainier, Maryland
Multnomah County, Oregon
The City of Naperville, Illinois
County of Nassau, New York
The State of Nebraska
The State of Nevada
New Castle County, Delaware
The State of New Jersey
New York State Office of Mental Health 🎓
State of New York 🎓
City of North Salt Lake, Utah
Northbrook (IL) School District #30
Ohio Building Authority
The State of Ohio
The State of Oregon ★
Overland Park, Kansas, City of
The City of Oxnard, California
County of Palm Beach, Florida
The City of Pasadena, California
Commonwealth of Pennsylvania
Philadelphia Water Department
The City of Philadelphia, Pennsylvania
The City of Phoenix, Arizona 🎓
The City of Pittsburgh, Pennsylvania
Polk County, Wisconsin
Polk County, Florida
The City of Portland, Oregon
Prince Georges County, Maryland 🎓
Prince William County, Virginia 🎓
The City of Provo, Utah 🎓
Commonwealth of Puerto Rico - Dept. of Natural & Enivr. Re
Queen Anne's County, Maryland
Rivervale Township of New Jersey
Rochester Community School Corp, Indiana 🎓
County of Rockland, New York
City of Sacramento, California
City of St. Louis, Missouri
The City of St. Paul, Minnesota
Salt Lake County, Utah
The City of San Bernardino, California
The City of San Diego, California
San Diego County, California 🎓
The City of San Jose, California
County of San Mateo, California
County of Santa Clara
The City of Santa Monica, California
The City of Santa Rosa, California 🎓
City of Scottsdale, Arizona
The City of Sierra Vista, Arizona
The City of Takoma Park, Maryland
The City of Tallahassee, Florida
The City of Tampa, Arizona
Tennessee State Department of Corrections
***Tennessee Valley Authority (TVA)**
Texas Department of Criminal Justice
The City of Tucson, Arizona
Air National Guard
Alabama Army National Guard
Alaska Army National Guard (State/Fed Space Included)
State of Arizona, DEMA, Arizona Army National Guards
Arkansas Army National Guard
US Army Aberdeen Garrison Proving Ground
The Army Environmental Policy Institute
US Army Fort A.P. Hill
US Army Fort Myer Military Community
US Army Fort Polk
US Army Garrison Fort Belvoir
US Army National Guard
Blue Ridge Parkway
US Bureau of Reclamation (US Dept of the Interior)
California Army National Guard
Carlsbad Caverns National Park
US Coast Guard Reserve Training Center
US Coast Guard Washington DC
Colorado Army National Guard (State/Fed Space Included)
Connecticut Army National Guard (State/Fed Space Included)
District of Columbia Army National Guard
Florida Army National Guard
Fort Carson, Headquarters
Georgia Army National Guard
Great Smoky Mountains National Park
Guam Army National Guard
Hawaii Army National Guard
Hill Air Force Base
Illinois Army National Guard
Indiana Army National Guard
Iowa Army National Guard
JN "Ding" Darling National Wildlife Refuge
Jimmy Carter Library And Museum
Kentucky Army National Guard
Lawrence Livermore National Lab (USDOE)
Louisiana Army National Guard
Maine Army National Guard
Malmstrom Air Force Base
Mammoth Cave National Park (US Nat Park Service)
Massachusetts Army National Guard
Michigan Army National Guard
United States Military Academy, West Point, NY
Mississippi Army National Guard
Missouri Army National Guard
Montana Army National Guard
US NASA Goddard Space Center
National Naval Medical Center
National Park Service - Denver Service Center 🎓
The National Security Agency
US Naval Academy
Naval Air Station (DOD), Willow Grove

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Nebraska Army National Guard
Nevada Army National Guard
New Jersey Army National Guard
New Mexico Army National Guard
Ohio Army National Guard
Oklahoma Army National Guard
Pennsylvania Army National Guard
US Postal Service Baltimore Associated Offices
U.S. Postal Service Baltimore - Distribution
Puerto Rico Army National Guard
Randolph Air Force Base ☞
South Carolina Army National Guard
Stanford Linear Accelerator Center (USDOE)
Tennessee Army National Guard
Uniformed Services University
Utah Army National Guard
Veterans Affairs Medical Center, Dwight D. Eisenhower
Veterans Affairs Medical Center, Palo Alto
Veterans Affairs Medical Center, Battle Creek
Veterans Affairs Medical Center, Decatur
Veterans Affairs Medical Center, Grand Island
Veterans Affairs Medical Center, Huntington
Veterans Affairs Medical Center, Indianapolis
Veterans Affairs Medical Center, Martinsburg
Veterans Affairs Medical Center, New Orleans
Veterans Affairs Medical Center, New York
Veterans Affairs Medical Center, Richmond ☞
Veterans Affairs Medical Center, Salt Lake City
Veterans Affairs Medical Center, San Diego
Veterans Affairs Medical Center, Seattle
Veterans Affairs Medical Center, Washington DC
Veterans Affairs Medical Center/West Side Chicago
Veterans Affairs Medical Ctr, Wadsworth/West LA
Vermont Army National Guard (State\Fed Space Included)
Virginia Army National Guard
Washington Army National Guard
Westover Air Reserve Base
Wisconsin Army National Guard
Ventura County, California
Virgin Islands ★
The Commonwealth of Virginia
Wasatch County School District ☞
The City of Washington, DC
City of White Plains, New York
State of Wisconsin

Green Lights Manufacturer Allies (234 total)

3M
A Weatherization Co/Awxco ☞
ACME Electric Corporation, Transformer Div.
ALP Lighting and Ceiling Products ☞
Address-o-lite ☞
Advance Transformer Co. ☞
Advanced Control Technologies, Inc. ☞
Advanced Environmental Recycling Corp.
Advanced Lighting, Inc. ☞
Advanced Luminescent Products
Aero-Tech Light Bulb Company
Alcoa Brite Products, Inc. ☞
Alkco
American Energy Management ☞
American Illuminetics Inc. ☞
American Lighting Corporation ☞
American Louver Company
American Scientific Lighting
Amerlux, Inc. ☞
Area Lighting Research ☞
Aromat Corporation
Badger USA ☞
Ballastronix Incorporated
Big Beam Emergency Systems ☞
Bright Side Lighting ☞
Brownlee Lighting ☞
Bryant Electric ☞
CEW Lighting Inc. ☞
CMB Associates, Inc. ☞
CPM Lighting
CSL Lighting Manufacturing, Inc.
Conservation Alliance
Conservation Technology, Ltd. ☞
Control Systems International ☞
Cooper Lighting
Crownlite Manufacturing Corporation ☞
Dark to Light, Inc. ☞
Daylight Company
Dazor Manufacturing Corporation
Decotex 2000 Corporation
Design By Nature, Limited
Dielectric Coating Industries ☞
Doolan Recovery Technologies
DuraLux Industries ☞
Duray Fluorescent Manufacturing ☞
Duro-Test Corporation
Dynamic Energy Products ☞
ESCO International ☞
Eclipse Technologies ☞
Edison Price Lighting
Electro-Tech's
Electronic Lighting Incorporated ☞
Emergi-Lite, Inc.
Enersave, Inc. (OH) ☞
Energy Conservation Development Corporation
Energy Dezign Corporation ☞
Energy Masters International, Inc. ☞
Energy Planning Associates
Entergy Integrated Solutions Inc. ☞
Entertainment Technology, Inc.
Environmental Energy Group
Evenlite
Exitronix - Div Of Barron Manufacturing ☞
FTI ☞
Feit Electric Co
Finelite
Flexiwatt, L.L.C.
Flexlite
Full Circle Incorporated ☞
Garcy/Systems Lighting Products
General Electric Lighting
The Genlyte Group
Global Recycling Technologies
Good Earth Lighting Company ☞
Guardian Corporation
Guardian Lighting Controls, Inc ☞
HE Williams, Inc. ☞
Harris Manufacturing, Inc. ☞
Hatch Transformer, Inc. ☞
Hetherington Industries, Inc.
Holcor ☞
Holophane Company Inc ☞
Honeywell, Inc. (Bloomington) ☞
Horizon/Lite Energy Ltd.
Howard Industries Inc ☞
Hubbell, Inc./Wiring Device Division
***Hubbell Incorporated, Lighting Division** ☞
IES, Incorporated
INCON Industries ☞
IceCap Industries, Inc. ☞
Industrial Energy Systems, Inc.
Indy Lighting ☞

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Italic Lettering Denotes Energy Star Small Business Participant

Integrated Power & Lites
Internat'l Energy Conservation Systems
International Lighting Manufacturing Company
Isolite Corporation
JJI Lighting Group, Inc.
Janmar Lighting
Johnson Controls, Inc. ★
Juno Lighting, Inc.
K-Lite, Division of ICI Acrylics
Kenall Lighting
Kilowatt Saver, Inc.
Kingtec, Inc.
The Kirlin Company ★
LSI Industries
LTI International, Inc.
LaMar Lighting Company
Ledalite Architectural Products
Legion Lighting Company, Inc.
Lexalite International
Light Corporation
Lighting Resources, Inc.
Lightly Expressed Ltd.
Lights of America
Lightscience Corporation
Litecontrol Corporation
Litetronics International
Lithonia Lighting
Lumasys Corporation
Lumetech Corp
Lumax Industries Inc
Lutron Electronics Inc.
Luxo Corporation
MTI International
Magnaray International
Magnetek, Inc.
Mark Lighting Fixture Company
Marlin Environmental Products Incorporated
Marvel Lighting Corporation
Mercury Recovery Services
Mercury Technologies of Minnesota, Inc.
Mercury Waste Solutions, Inc.
MetalOptics, Inc.
MicroLite Corp., Subsidiary of Pittway
Midwest Conservation Systems
Mor-Lite
Motorola Lighting, Inc.
Mule Emergency Lighting Inc.
MyTech Corporation ★
NRG Lighting Inc. ★
National Cathode Corporation
National Lighting Company, Inc.
Natural Lighting Company
Norbert Belfer Lighting
Novitas, Inc.
OSRAM Sylvania, Inc.
Optek Design & Manufacturing
The Original Cast Lighting
PEC Lamp
PLC-Multipoint
Pacific Scientific, Fisher Pierce Division
Paragon Electric Company, Inc.
Parrish Lighting & Engr
Pass & Seymour/Legrand
Pathway Lighting Products, Inc.
Philips Lighting Co.
Phillips Lighting Electronics Company
Powerline Communications
Pre Finish Metals
Prescolite Controls, Inc
The Pritchett Wilson Group Incorporated
Progress Lighting, Inc
Prolume Corporation
Q Technology, Inc.
Quality Lighting
RAB Electric Manufacturing Company
Recyclights
Reflect-A-Light, Inc.
Remtec Systems
Renova Lighting
The Robert Group
Robertson Transformer Company
Roth Brothers Inc ★
RoyalLite Manufacturing & Supply Corp.
Ruud Lighting ★
Southland Industries
SK America, Inc.
SPI Lighting, Inc.
Salesco Systems USA
Save-A-Watt, Inc.
Scientific Component Systems
Sea Gull Lighting Products
Self-Powered Lighting, Inc.
Sensor Switch
Sharlin-Lite
Siebe Environmental Controls, Illinois
Simkar Lighting Fixture Company, Inc.
Skanda Lights
So-Luminaire Daylighting Systems Corporation
Solar Electric Systems
Solar Kinetics
Solar Outdoor Lighting
Solium, Inc
Spaulding Lighting, Inc
***Spent Lamp Recycling Technologies**
Sportlite, Inc.
Standard Enterprises, Inc.
Steelcase Inc ★
Sterling, RMC
Stocker & Yale
Systematix, Inc.
TMP, Inc.
TORK, Inc.
TSAO Designs and CSL
TechBrite
Techmedia Lighting, Inc.
TechniLite Systems
Teron Lighting
Thomas Industries, Inc.
Thomas and Betts
Toshiba America Cons Prod
Triad Technologies
Trimblehouse Corporation
Tristar Lighting Co.
Trojan, Inc.
Tropical Lighting
UNENCO
USES, Inc.
Ulster Precision Inc
Valmont Electric
Venture Lighting International
Videssence, Inc.
Visa Lighting Corporation
Vision Impact Corporation
Visual Images, Incorporated
WF Harris Lighting
Waldmann Lighting Company
Warner Technologies
The Watt Stopper Inc.
Wellmade Metal Products Co
Wismarq Light Co.

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X-Tra Light Systems, Inc. 🎓
Zumtobel Lighting

Green Lights Utility Allies (73 total)

Alabama Power Company
Allegheny Power Service Corporation
American Electric Power Service Corp. ★
Arizona Public Service Company ★
Atlantic Electric
Baltimore Gas and Electric Co.
Bangor Hydro Electric
Boston Edison Company
Central Illinois Light Company (CILCO)
Central Illinois Public Service Company
Cinergy
Commonwealth Electric Company
Concord Municipal Light Plant
Consolidated Edison of New York, Inc.
Detroit Edison Company
Duke Power Company 🎓
The Empire District Electric Company
GPU Energy
The City of Georgetown, Texas Utility 🎓
Georgia Power Company
Gray's Harbor County PUD #1
Green Mountain Power Corporation 🎓
Greenville Utilities Commission 🎓
Gulf Power Company
Hawaiian Electric Company, Inc.
Idaho Power Co
Indiana Municipal Power Agency 🎓
Indianapolis Power & Light
Kansas City Power & Light ★
Long Island Lighting Company (LILCO)
Los Angeles Department Of Water & Power
Mason County Public Utility District (PUD) No. 3
Mississippi Power
Moorhead Public Service
NEES Companies
Nevada Power Company
New York Power Authority 🎓
Northeast Utilities
Northern States Power Company (Gas)
Norwood Municipal Light Department
Old Dominion Electric Cooperative 🎓
Omaha Public Power District 🎓
Orange and Rockland Utilities
Pacific Gas & Electric 🎓
Pacific Power
Pike County Light and Power Co. 🎓
Port Angeles City Light Department ★
Portland General Electric Company ★
Potomac Electric Power Company (PEPCO)
Puerto Rico Electric Power Authority
Puget Sound Power & Light Co
Richmond Power & Light Company
Rockland Electric Co. 🎓
SMUD (Sacramento Municipal Util Dist)
City of St. Charles Electric Utility 🎓
Salt River Project 🎓
San Diego Gas & Electric ★
Savannah Electric Power 🎓
South Carolina Public Service Authority
Southern Maryland Electric Cooperative
Springfield Utility Board
Taunton Municipal Lighting Plant 🎓
Tucson Electric Power Company
The UNITIL System of Companies
Union Electric Company
United Illuminating Company
Utah Power
Virgin Islands Water & Power Authority
Virginia Power ★
Wisconsin Electric Power Company 🎓
Wisconsin Power & Light Co 🎓
Wisconsin Public Power, Inc. System 🎓
Wisconsin Public Service Corporation

Green Lights Distributor Allies (149 total)

A M Electric Company Inc 🎓
ANESCO
ARGO
Active Electric Supply 🎓
Advance Electrical Supply 🎓
Adventure Lighting Supply, Ltd. 🎓
Aladdin Lighting Supply 🎓
Alameda Electrical Distributors, Inc.
All Lighting Inc. 🎓
Almeida Electrical, Inc.
American Energy Control of Boston, Inc
American Light, Inc.
American Lighting & Electric Supply Co. 🎓
Archway Lighting Supply Inc. 🎓
Atlantic Lighting and Supply Co. (NJ) 🎓
Atlantic Lighting and Supply Co. (GA) 🎓
Barbizon
Beard Campbell Company
Border States Electric Supply
Braid Electric Company
Branch Energy Systems 🎓
Bright Electrical Supply Co.
Buckles-Smith Electric Co. 🎓
The Bulb Man, Inc. 🎓
CIC Supply
CN Robinson Lighting Supply
Capitol Light and Supply Company
Cardello Electric Supply 🎓
Citilights Lighting, Inc.
City Lighting Products Company 🎓
Codale Electric Supply, Inc. 🎓
Commercial Lighting of Virginia, Incorporated
Con/Serve Electrical Supply Company
Conserve-A-Watt Lighting 🎓
Consumer Lighting Products 🎓
Cooper Electric Supply Company
Corporate Energy Management Systems, Inc. 🎓
Dauphin Electric
Debenham Electric Supply Company 🎓
Deeter Lighting 🎓
Dixie Electric Supply Corporation
E. Sam Jones Distributor, Inc.
EESCO
Eagle Electric Supply Company, Inc.
Electric Supply, Inc. (AZ)
Electric Supply, Inc. (OK) 🎓
Elliott Electric Supply
Energy Saver Lighting Company
Eoff Electric Company
Erik Lighting, Inc.
First Light Lighting Systems
Fitzpatrick Electric Supply 🎓
Five Star Lighting
Fred Davis Corporation
Fromm Electric Supply Company
GW Supply Company
Gabco Enterprises, Inc. 🎓
General Products & Supply, Inc.
Goforth Electric Supply 🎓

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Good Friend Electric
Grahl Electric Supply Company
Grand Light & Supply Co., Inc.
Graybar Electric Company
Gross Electric
H & H Industries
Harco Distributing Services
Hart Lighting & Supply
Hite Company, The
Holmes Distributors
Illuminating Technologies
Independent Electric Supply Co.
Inland Lighting Supplies, Inc.
JH Larson Electrical Company
Kendall Electric
Kentucky Lighting & Supply, Inc.
King Lighting Supply
Kirby Risk Supply Company
*La Crane
Laser Lighting & Electrical Supply, Inc.
Lektron Industrial Supply, Inc.
Leslie Electric Company
Light Bulb Supply Company
Lighting Supply Company
Lighting Systems Too!
Litemor Distributors of Boston Ltd
M & M Electric
Major Electric Supply, Inc.
Matsushita Home and Commercial Products Co
Mayer Electric Supply Company, Inc.
Michigan Chandelier
Mid Atlantic Lighting
Mid-West Wholesale Lighting Corporation
Midtown Electric Supply Corporation
Missouri Valley Electrical Company
Montclair Distributing
Muska Lighting Center
National Electric Supply
North Coast Electric Company
Nu-Lite Electrical Wholesalers, Inc.
OK Electric Supply Company
Orange Coast Electric Supply
FEDCO
PJS
Pacific Electrical Supply
Platt Electric Supply
Premium Lighting Supply
Queen City Electric Supply
Raymond deSteiger, Inc.
Reyvern Lighting Supply Company, Inc.
Regency Lighting
Retrofit Design Lighting
Rockingham Electrical Supply
Rumsey Electric Company
Ryall Electric Supply Company
Schaedler Brothers, Inc.
Seamans Supply Company, Inc.
Shealy Electrical Wholesalers, Inc.
Southland Electrical Supply Company
Spring Electric Supply
Standard Electric Supply
Stanion Wholesale Electric
Starbeam Supply Company
Steiner Electric Company
Stitzell Electric Company
Stokes Electric Co
Stuart C Irby Co.
Summit Electric Supply
Superior Lighting Company
Swift Electrical Supply Company
Taylor Electric Supply, Inc.
Tecot Electric Supply Company
Tri-State Light & Energy, Inc.
Tristate Electrical Supply Company, Inc.
US Lamp
United Electric Supply
United Electric Supply Company
Villa Lighting Supply, Inc
Voss Lighting
WESCO Distribution-Headquarters Division
WW Grainger Incorporated
Warren Electric Company
Western EXTRALITE Company of Kansas City
Western EXTRALITE Company of St. Louis
Whitehill Lighting & Supplies, Inc.
Wholesale Electric Supply Company
Wiedenbach-Brown Company, Inc.
Williams Supply
Wolff Brothers Supply
YESCO

Green Lights Lighting Mgt Company Allies (127 total)

A 1 Lighting Service Company
ABD Lighting Management Co.
Advanced Energy Management Corporation
Advanced Energy Systems, Inc.
Advanced Lighting Applications
Advanced Lighting Products Limited
Aetna Corporation
Aetna Lighting and Energy Conservation
All Tech Lighting
Alva Lighting
AmTech Lighting Services ★
AmTran
American Lighting Inc
Applied Energy Management, Inc.
Arc Electric Company
Avtech, Inc.
BLI of Minnesota
Barney Roth Co
Belco Electric, Inc.
Boston-Finney
Brayer Lighting, Inc.
Broadway Lighting Services
CES/WAY International, Inc.
CF Lighting Supplies
CLS Facilities Maintenance
CMC Energy Services
Candela Systems Corporation
Cherry City Electric Lighting Services
Chicago-Edison Corporation
Colorado Lighting
Coneco Corporation
Conserve Electric Company, Inc
Creative Lighting Maintenance
Dixie Design Group
E-Technologies
E-Finity Energy, LLC
ESCO Energy Services Company
Earth Protection Services, Inc.
Earth Savers, LLC
Earthwell International Technologies, Inc.
Efficient Lighting & Maintenance Incorporated
Electric Conservation and Supply Company
Energy Concepts, Inc.
Energy Conservation Allies, Inc.
Energy Conservation Hawaii
Energy Controls & Concepts
Energy Enterprise Incorporated

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Bold Lettering Denotes Energy Star Buildings Participant
Italic Lettering Denotes Energy Star Small Business Participant

Energy Matrix 🎓
Enersave, Incorporated (NY)
Environmental Energy 🎓
Environmental Energy Partners Incorporated
FMS Lighting Management Systems, Inc. 🎓
Fluorescent Maintenance Company 🎓
Fluoresco Lighting-Sign Maintenance Corp.
Fravert Services 🎓
GAR Electronics 🎓
GEC Lighting Supply
General Lighting and Sign Services, Inc. 🎓
Genesis Lighting Management Services, Inc.
Glace Energy, Inc. 🎓
GreenTech Energy Services, Inc.
HEC, Inc.
Hilliard Electric
Hucker Electric Company
Illumelex Corporation 🎓
Illumetek Corporation 🎓
*Imperial Lighting Maintenance Co 🎓
Innovative Lighting Services 🎓
Integrated Lighting & Energy Company
Judisch Photo and Electronics
Kenetech Energy Management, Inc.
LighTec, Inc. 🎓
Light, Inc. 🎓
Light Source 🎓
Lighting Dynamics, Inc. 🎓
Lighting Images Technology
Lighting Maintenance & Service, Inc. 🎓
Lighting Maintenance, Inc.(Ill) 🎓
Lighting Management Consultants 🎓
Lighting Management, Inc.
Luminaire Service, Inc. 🎓
Lupo & Associates 🎓
MTI Energy Management in Lighting 🎓
Master Lighting Services 🎓
Mira Lighting & Electric Service, Inc 🎓
Murphy Electric Maintenance Co. 🎓
National Energy Services Incorporated 🎓
New Mexico Energy Consultants 🎓
Nite Lites
North American Energy Systems
North American Lighting, Inc. 🎓
Optimal Technologies
Ott Light Systems Incorporated
Pacific Energy Management Corporation
Parke Industries, Inc 🎓
Planned Lighting, Inc. 🎓
Power Savers, Inc. 🎓
Powercon, Inc. 🎓
Prime Electric Company
Primo Lighting Management 🎓
Prolite Lighting & Sign Maintenance ★
Proven Alternatives, Inc.
Retro Task
Sabo and Associates, Inc.
Shane Companies 🎓
Sica Electrical & Maintenance ★
Sigal Environmental Company
Southern Energy Technologies
Spectrum Lighting Technologies 🎓
Stay-Lite Lighting Service 🎓
Strategic Resource Solutions, INC
Suburban Lighting, Inc. 🎓
Superior Light & Sign Maintenance Co. 🎓
Sylvania Lighting Services
Synergy Lighting Corporation 🎓
System Solutions of Georgia, Inc. 🎓
TechLite Applied Sciences, Inc.
Thayer Enterprises 🎓
Ultimate Lighting Systems, Inc. 🎓
United Energy Associates 🎓
Unitrac Energy Management Company 🎓
Universal Lighting Services 🎓
Vista Universal, Inc. 🎓
WAC Lighting
West Indies Resource Management Corporation
Wheatstone Energy Group, Inc. 🎓
Xenergy 🎓

Energy Star Buildings Allies (161 total)

A-Valey Engineers
ACCO
ACE Electrical Service, Inc.
ADA Systems
AF Smith Electric
Acutherm
Advance Transformer Co. 🎓
Advanced Energy Management Corporation
Advanced Energy Systems, Inc.
Advanced Lighting Products Limited 🎓
*Airgo Environmental Incorporated
Alproem Engineering Services
American Chemical Company
American Light, Inc.
Apache Products Company
Area Energy Management Services
Atlantic Energy
BGE Energy Projects and Services Incorporated
Becharach Incorporated
Baltimore Air-Coil Company
Belco Electric, Inc. 🎓
Big Beam Emergency Systems 🎓
C & M Lighting Technologies
CEC Consultants Company, Inc.
CEMC, Inc
CES/WAY International, Inc. 🎓
CF Lighting Supplies
CMB Associates, Inc. 🎓
Candela Systems Corporation
Carter and Burgess Incorporated
Colorado Lighting 🎓
Compass Management & Leasing, Inc. - Dallas Region
Connolly Engineering Incorporated
Control Systems International 🎓
Demand Management Institute
Detroit Edison Company
E-Technologies
E-Three
E-Finity Energy, LLC 🎓
EM Electric Corporation
EUA Cogenex Corporation, Massachusetts
Eagan and Associates Architects
Earth Protection Services, Inc.
Earthwell Energy Management, Inc.
Eastern Energy Services, Inc.
Edison Power Technologies
EnerCon, Inc.
Energy Conservation Allies, Inc.
Energy Data Company, Inc.
Energy Matters
Energy Systems Group
Energy USA
Engineered Environments
Engineering Excellence Inc
Entergy Integrated Solutions Inc. 🎓
Enterprise Corporation
Equator Corporation

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*Eye Lighting International
Facility Works
Florida Lighting
Georgia Trane
Global Facility Solutions
Global Tech Services
Green Mountain Power Corporation
HOU-TRA International
Hetherington Industries, Inc.
Honeywell, Inc. (Bloomington)
Hottel Environmental Group
*Hubbell Incorporated, Lighting Division
INOVA Research Group
Illingworth Corporation
Illumalex Corporation
*Imperial Lighting Maintenance Co
Innovative Energy Solutions
International Water Management, Inc.
J.R. Yago and Associates
Johnson Controls, Inc., Maryland Area Office
Judisch Photo and Electronics
KVAR Energy Savings, Inc.
Kurtzon Lighting
Lane Energy Services
LeChase Construction
LighTec, Inc.
Lighting Management Consultants
Lighting Systems Upgrade
Lighting Technologies LLC
Lighting and Service Company, Inc.
Los Gatos Air Conditioning
Lumetech Corp
MOLETEC Corporation
MaGrann Associates
Magnetek, Inc.
McKenney's, Inc.
Mercury Technologies of Minnesota, Inc.
Metro Energy Corporation
Miceli Energy Engineering
Mid Atlantic Energy Concepts Incorporated
*Miller Lighting & Energy Inc.
Modern Edison, Oklahoma
Monolithic Structures Corporation
Montclair Distributing
Moorhead Public Service
Motector Systems Incorporated
Munters Corporation
Nextek Power Systems, Inc.
North Carolina Electric Membership Corporation
Northgate Electric
Nu-Lite Electrical Wholesalers, Inc.
Nu-Way Lighting Incorporated
OK Electric Supply Company
Old Colony Electrical Company, Inc.
OmniComp, Inc.
Optimal Technologies
Owens Services Corporation
Powerlight Corporation
Premium Lighting Supply
Prime Electric Company
Proven Alternatives, Inc.
Q Technology, Inc.
Quality Lighting Services
Quarry Systems, Inc.
Rayvern Lighting Supply Company, Inc.
Recyclights
Retro Tesk
River Valley Electric Motor Rewind & Repair, Inc.
Roof Science Corporation
S.C.F., Inc.
Southland Industries
SRC Systems Incorporated
Savings Technology
Seaboard Electrical Services, Inc.
Servidyne
Sibley Services
Sierra Power Group Inc.
Solar Outdoor Lighting
Solar Utility Incorporated
Southern Development & Investment Group
Southern Energy Technologies
*Spent Lamp Recycling Technologies
Spring Electric Supply
Sterling Industries
Strategic Resource Solutions, INC
Superior Energy Service
Syska & Hennessy / CEM
TDIndustries
TerraPro Property Management Company
Tesser Consulting Group
Therm-O-Lite
Tooley & Company
Total Lighting Service, L.L.C.
Tozour Energy Systems
The Trane Company, Applied Global Systems
United Energy Associates
Verle A. Williams & Associates, Inc.
Viron Energy Services
W B Guimarin and Company, Inc.
Wheatstone Energy Group, Inc.
Wholesale Electric Supply Company
Wiegmann and Associates
Xencom Systems, Inc.
Xenergy

Green Lights Endorsers (301 total)

Aerospace Industries Association of America
Airports Council International - North America
Allegheny Health Education Research Foundation
Alliance for Affordable Energy
Alpharetta Envir. Services & Alpharetta Clean & Beautiful
American Advertising Federation
American Assn for the Adv of Science
American Council for an Energy Eff Econ
American Gas Association
American Hospital Association
American Hotel & Motel Association
American Institute of Architects Georgia
American Institute of Architects, Philadelphia
American Institute of Architects
American Lighting Association
American Littoral Society
American Lung Association
American Public Power Association
American Rivers
American Society of Healthcare Engineers for AHA
American Society of Interior Designers
American Trucking Association
Anchorage Chamber of Commerce
Architects, Designers, & Planners for Social Resp
Arizona Hospital and Healthcare Association
Arkansas Hospital Association
AR State Chamber of Commerce/Assn Ind of AR
Asheville Area Chamber of Commerce
Assn of Professional Energy Consultants (APEC)
Associated Industries of Massachusetts
Associated Students of UC Berkeley
Association for Facilities Engineering
Association of County Commissioners of Georgia

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Association of Delaware Hospitals
Assn of Demand-Side Mgt Professionals
Association of Energy Engineers
Association of Higher Education Facilities Officers
Association of Professional Energy Managers
Association of Science-Technology Centers
Association of Washington School Principals
Atlanta Committee for the Olympic Games
Atlanta Regional Commission
Audubon Society of New Hampshire
Audubon Society of New York State, Inc.
Automative Wholesalers of Illinois
Boulder County Clean Air Consortium
Boulder Energy Conservation Center (BECC)
Business for Social Responsibility
California Chamber of Commerce
California Department of Education
California Municipal Utilities Association
California Society for Hospital Engineering, SF
California Society of Hospital Engineering, Inc.
California State Association of Counties
Casino Association of New Jersey
Catholic Health Association of the United States
Center For Marine Conservation
Center for Industrial Services, University of Tennessee
Citizen Action
Clean Air Cab Company, Inc.
Clean Air Council
Clean Ocean Action
Clean Water Action
The Climate Institute
Coloradans for Clean Air
Colorado Hospital Association
Commonsense
Community Associations Institute
Concern Inc.
Connecticut Business & Industry Association
Consulting Engineers Council of Metro Washington
Consumer Counsel, State of Ohio
Council of State Governments
Council of Teaching Hospitals
DC Chamber of Commerce
Delaware State Chamber of Commerce
E2: Environment and Education
Earth Share
Ecologix
Edison Electric Institute
Electric Ideas Clearinghouse
The Electrical Assn of Philadelphia 🎓
Electronic Industries Association
Environmental Action
Environmental Action Club of Skidmore College
Environmental Awareness Foundation
Environmental Business Association
The Environmental Exchange
Environmental Law Institute 🎓
Environmental Leadership
Environmental and Energy Study Institute
Esatech C.A.
Evangelical Environmental Network
Federated Garden Club of Vermont
Federated Garden Clubs of Connecticut
Federation of American Health Systems
Food Marketing Institute
Friends of the Earth
Garden Club Federation of Massachussetts
Georgetown University Student Assocation
Georgia Hospital Association
Georgia Municipal Association
The Global Cities Project
Greater Atlanta Chamber of Commerce
Greater Dallas Chamber of Commerce
Greater Jacksonville Area Hosptial Council
Greater Miami Chamber of Commerce
Greater Philadelphia Chamber of Commerce
Greater Philadelphia Hotel Engineers Association
Greater Seattle Chamber of Commerce
Green Hotels Association
Gwinnett County Safety Professionals Association
HVS Eco Services
Hampshire College Pugwash
Hawaii Hotel Association
Historic Bartram's Garden
Home Center Institute
Hospital Association of Central Ohio
Hospital Association of Pennsylvania
Hospital Council of Greater Milwaukee
Hospital Council of Western Pennsylvania
Hospital Engineers of Southwestern PA
Hospital Shared Services
Illuminating Engineering Society of North America
Industrial Lighting Distributors of America
Institute for Alternative Futures
Inst for Coop in Environmental Management
Institute for Local Self-Reliance
Institute of Real Estate Management
Int'l Brotherhood of Elec Workers Local Union #98
International Facility Management Association
International Institute for Energy Conservation 🎓
Iowa Association of Business & Industry
Iowa Hospital Association, Inc.
Izaak Walton League 🎓
Kansas City Area Hospital Association
Kent State University Undergrad. Student Senate
Kentucky Pollution Prevention Center
Land-of-Sky Regional Council
Lighting Design Lab
The Lighting Resource
Long Island Associations, Inc.
Lorax Environmental Club - NCSU
Los Angeles Area Chamber of Commerce
Louisiana Hospital Association
MTSU Lambda Association
Maine Chamber of Commerce and Industry
Maine Hospital Association
Maine Municipal Association
Maryland Association of Counties
Maryland Chamber of Commerce
Maryland Hospital Association
Maryland Municipal League
Massachusetts Municipal Wholesale Electric Co.
Metro Washington Council of Governments
Metropolitan Detroit Building Superintendents Association
Metropolitan Energy Center
Miami Museum of Science and Space
Middlebury Student Government Association
Minnesota Chamber of Commerce
Minnesota Environmental Initiative
Minnesota Hospital and Healthcare Partnership
MS Technical Assistance Program
Missouri Energy Resources Project
Montana Hospital Association
Mt. Washington Valley Chamber of Commerce
NALMCO
NECA, Illinois Chapter
NPFMA
National Association for Environmental Management
National Association of Chain Drug Stores
National Association of Counties (NACo)
National Association of Electrical Distributors

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National Association of Physicians for the Environment
Nat Assn of Power Engineers, Met Miami FL Ch #4
National Assn of Power Engineers, NY Chap #24
National Association of State Facilities Administrators
National Association of Towns and Townships
Nat Assn of Regulatory Utility Commissioners
The National Commercial Builders Council
National Conference of States
Nat Cncl of State Garden Clubs, N England Region
National Earth Science Teachers Association
National Electrical Contractors Association
National Electrical Manufacturers Assn
National Energy Management Institute
The National Lighting Bureau
National Restaurant Association
National Retail Federation
National Retail Hardware Association
National Society of Prof. Engineers, NCSU Chapt.
Nevada Recycling Coalition
New Hampshire Business & Industry Association
New Hampshire Federation of Garden Clubs
New Hampshire Hospital Association
New Jersey Business & Industry Association
New Jersey Hospital Association
New Mexico Hospitals and Health Systems
North Carolina Consumers Council
North Carolina Hospital Association
North Carolina Solar Energy Association
Northeast Energy Efficiency Council
Northeast Public Power Association
Northern Light Section IES
Northwest Air Pollution Authority
Northwest Power Planning Council
Northwest Public Power Association
Northwood NH Conservation Commission
Ohio Citizens for Responsible Energy
The Ohio County Camping Association
Ohio Environmental Council
Ohio Hospital Association
Ohio Public Facilities Maintenance Association
Oklahoma Hospital Association
OmniComp, Inc.
Oregon School Facilities Management Association
OR Society for Hospital Engineering
Oregon State Superintendent of Public Instruction
The Organization for Green Living: Alfred University
The PENJERDEL Council
Pacific NW Pollution Prevention Research Ctr
Pacific Northwest Ski Areas Association
Pennsylvania Association of School Business Officials
Pennsylvania Gas Association
Planet Earth Environmental Services
The Professional Assn of Innkeepers Int'l
Public Citizen
Public Technology, Inc.
Puerto Rico Hospital Association
The Purchase Connection
RI Federation of Garden Clubs, Inc.
Radio Catskill (WJFF, Jeffersonville)
Rails-to-Trails Conservancy
Regional Air Pollution Control Agency
Remodeling Contractors Association of America
Responsible Energy of Hampshire College
The Rice University Student Association
Sacramento Metropolitan Chamber of Commerce
Saddleback Mountain Lions Club of NH
San Francisco Chamber of Commerce
San Jose Metropolitan Chamber of Commerce
Science Teachers Association of New York State
Science Technical Assistance Center
Seattle Area Hospital Council
Smaller Business Association of New England
Society for the Protection of NH Forests
Soil and Water Conservation Society
South Carolina Hospital Association
Southeastern Environmental Resources Alliance
Southern Appalachian Man & the Biosphere Coop
Southern Appalachian Mountains Initiative
Spectrum of Light Youth March Earth Day XXV
Spokane Chamber of Commerce
Student Assn of SUNY at Oswego
The Student Assn of the GW University
Student Envir. Action Coalition, Univ. of Denver
Student Environmental Action Coalition
Student Environmental Outreach Program
Student Government Association of Berea College
Student Government Assn of Skidmore College
Student Pugwash USA
Student Senate of Alfred University
Students for an Energy-Efficient Environment
Sun Day Campaign
Tampa Bay National Estuary Program
Tennessee Hospital Association
Tennessee Small Business Development Center
Texas Association of Business
Tucson/Pima County Metropolitan Energy Commission
US Green Building Council
US Telephone Association
Union of Concerned Scientists
United Garden State Restaurant & Lodging Assn
University College Administration at University of Denver
University System of Georgia Board of Regents
University of Colorado Environmental Center at Boulder
University of Maine Student Government
University of Oklahoma Student Assn
Vermont Businesses for Social Responsibility
Vermont Student Environmental Program
Virgin Islands Retailer's Association
Virginia Association of Counties
Virginia Chamber of Commerce
Virginia Hospital Association
Virginia Manufacturers Association
Virginia Municipal League
WRATT Foundation, The
The Wagner Group, Inc.
Washington Assn of Maintenance & Ops Administrators
Washington Association of School Admin
Washington Association of School Business Officials
Washington State Hospital Association
Washington State School Directors Association
WA State Superintendent of Public Instruction
Waste Reduction Action Coalition
West Michigan Environmental Action Council
West Virginia Manufacturers Association
Wildlife Conservation Society
Wisconsin Center for Demand-Side Research
World Resources Institute
York Foundation

Energy Star Buildings Endorsers (56 total)

Alliance to Save Energy
Alpharetta Envir. Services & Alpharetta Clean & Beautiful
American Consulting Engineers Council
American Council for an Energy Eff Econ
American Trucking Association
Arizona Hospital and Healthcare Association
Arkansas Hospital Association
Association of Energy Services Professionals
Association of Professional Energy Consultants

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Association of Schools of Public Health
Building Officials and Code Administrators
California State Association of Counties
Catholic Health Association of the United States
Clean Water Action
The Climate Institute
Colorado Hospital Association
Council of Teaching Hospitals
E2: Environment and Education
***Electric Power Research Institute**
Elizabeth River Project
Environmental Awareness Foundation
Evangelical Environmental Network
Florida Hospital Association
Georgia Hospital Association
Greater Philadelphia Hotel Engineers Association
Green Hotels Association
Green Seal
Hawaii Hotel Association
Institute of Real Estate Management
International Council of Shopping Centers
International Institute for Energy Conservation
Izaak Walton League
Kentucky Pollution Prevention Center
***Local Government Commission**
Long Island Associations, Inc.
National Association of College and University Business Ofcr
National Association of Physicians for the Environment
National Association of Power Engineers
National Association of State Facilities Administrators
National Electrical Contractors Association
National Electrical Manufactures Represantatives Association
National Society of Architectural Engineers
Nevada Association of Hospitals and Health Systems
New Hampshire Business & Industry Association
New Hampshire Hospital Association
New Jersey Business & Industry Association
North Dakota Healthcare Association
Northern Metropolitan Hospital Association
OHA: The Association for Hospitals and Health Systems
Oregon School Facilities Management Association
Puerto Rico Hospital Association
Refrigeration Services Engineers Society
Utah Association of HealthCare Providers
Vermont Businesses for Social Responsibility
Virginia Association of Counties
Wyoming Hospital Association

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Q14.2 Please document the statement that "they could reduce the carbon dioxide emissions due to the energy used in commercial buildings by 35 percent and reduce commercial buildings' energy bills by $25 billion per year."

A14.2 See attachment, "ENERGY STAR BUILDINGS -- Showcase Buildings Partners". The charter("showcase") partners in EPA's Energy Star Buildings and Green Lights program documented a median energy savings and greenhouse gas reduction of 35%.

Showcase Building Project Results

ENERGY STAR Buildings Example Showcase Buildings Partners				Annual Energy Use All Fuels (kBtu/Sqft-Yr)		
Partner	**Building**	**Location**	**Sq. Ft.**	**Before**	**After**	**Savings**
American Standard Company	Technology Center	LaCrosse, WI	200,000	86	68	21%
Boccardo Properties	Community Towers Buildi	San Jose, CA	350,800	68	43	37%
Douglas County Government	Old Courthouse and Justice	Roseberg, WA	254,000	82	46	44%
Louisville Municipal Sewer Dist.	Headquarters Building	Louisville, KY	75,800	83	46	45%
Montgomery County Govt.	Hungerford Office Building	Rockville, MD	83,000	153	94	39%
Southern Cal Gas Company	Energy Resource Center	Downey, CA	44,000	79	57	28%
St. Charles Medical Foundation	St. Charles Medical Center	Bend, OR	259,085	398	228	43%
Vought Aircraft Company	Buildings 7 & 49	Dallas, TX	132,000	65	43	34%
Warner-Lamert Company	Headquarters Building 86	Morris Plains, NJ	125,000	98	62	37%
The Washington Times	Headquarters Building	Washington, DC	122,643	138	91	34%

Median energy savings for all Showcase Buildings Participants: 35%

Total energy consumption, 1996. $110 billion — source Annual Energy Outlook 1996 (1994 dollars), commercial sector adjusted to include industrial floorspace
potential energy savings 35% — source Showcase Buildings
potential energy bill savings $38.5 billion
"$25 billion" used to ensure the estimate is conservative

U.S. EPA, OAR, APPD, Energy Star Buildings and Green Lights Program

Q14.3 Please provide the level of funding for EPA's Green Lights and ENERGY STAR Buildings Program in FY 1997 and FY 1998, and the amount requested for FY 1999.

A14.3 FY 1997 = $22,905.000
FY 1998 = $24,372,000
FY 1999 = not a line item

In the FY 1999 budget proposal, the Green Lights and Energy Star Buildings Program is one component of the "Buildings" line item (see response to Question 29).

Q14.4 Please identify all recipients of the funds--by fiscal year and by amount for each recipient--identified in the response to question 14.3 above.

A14.4 EPA interprets this question to be based on the misconception that EPA provides financial assistance to partners in this program. EPA does not provide any funding to program participants. Instead, EPA uses its funding to disseminate reliable financial and technical information to program partners to assist them in making better decisions for investing their own money. With improved information through voluntary partnerships, companies are able to make investments that simultaneously reduce greenhouse gas emissions and reduce energy bills.

Climate Wise

Q15. On pages 6 and 7 of your written testimony, you state:

"Climate Wise. Since 1994, 392 companies, representing 8.5% of U.S. industrial energy use, have joined Climate Wise, including: British Petroleum, DuPont, 3M, Johnson & Johnson, General Motors, Boeing and more than 200 small and medium-sized companies. Companies have submitted Action Plans detailing more than 700 emissions reductions actions that they estimate will reduce greenhouse gas emissions by more than 5 million metric tons of carbon equivalent by the year 2000. In the process they expect to save more than $300 million."

Q15.1 Please identify the 392 companies that have joined Climate Wise.

A15.1 A current list of the 400 Climate Wise Company Partners listed both in alphabetical order and by State is attached.

Climate Wise Partners

3M Austin Center
3M Company
ABC Wholesale Roofing
Abe Krasne Home Furnishings
Ace Galvanizing
Acme Bread Company
ACORN
Adapto Storage Products
Advance Heli-Welders & Manufacturing Company, Inc.
Advanced Cast Products/Belcher Corp.
Advanced Circuit Technology
Advanced Micro Devices, Inc.
Air Products & Chemicals
Ajinomoto USA, Inc.
Allergan, Inc.
American Cat Emporium & Wood Products
American Soil Products
Andros Incorporated
Anheuser-Busch Companies
Anitec, International Paper
Apache Products Company
Apollo Printing
Apple Computer, Inc. - Austin
Applied Materials, Inc. - Austin
Arizona Lithographers
Arizona Portland Cement Company
Asarco, Inc. - Globe Plant
Ash Grove Cement Company
Ashforth Pacific
Ashland Chemical, Inc.

Association of American Railroads
AT&T
Atlas Copco Comptec, Inc.
Austin Commercial, Inc.
Austin Quality Foods Inc.
Autumn Harp, Inc.
Aveda Corporation
Azdel, Inc.
Bagel Works, Inc.
Ball Packaging Corporation
Barbour Plastics, Inc.
Barkow Manufacturing Company, Inc.
Baxter Healthcare Corporation
Baxter International
Bayview Technology
Beaulieu Vineyard

Behlen Manufacturing Company
Beringer Vineyards
Berkeley Mills East West Furniture Design
Bethlehem Steel Corporation
Blaser Die Casting
Blodgett Oven Company
Blumenthal Export, Inc.
Boeing Company, The
Boston Retail Products
BP America Inc.

Branson Ultrasonics Corporation

Brewer Automotive Components
Briggs & Stratton Corporation
Bristol-Myers Squibb Company
Broyhill Company
Buena Vista Winery, Inc.
Buffalo County

Bureau of Correctional Enterprises
Burrito Brothers, Inc.
Calaveras Cement Company
California Portland Cement Company
Capitol Aggregates Ltd.
Capitol Circuits Corporation
Captive Plastics, Inc.
Cargill, Inc.
Cascade General, Inc.
Catamount Brewing Company

Central Confinement Service, Ltd.
Central Metal Finishing, Inc.
Central Products Company - Brighton
CF&I Steel, L.P.
Cheese Cake City, Inc.
Cirtronics
Clearflow Valves
Clermont, Inc.
Colorado School of Mines
Colorado's Ocean Journey

Columbia Steel Products Company
Conant Custom Brass, Inc.
Concord Beverage Company
Coors Brewing Company
Cosmair, Inc. - Clark Facility

Cosmair, Inc. - Somerset Facility
Cranston Print Works
Cross Creek Apparel, Inc.

Sheet1

Crown Battery Manufacturing Company
Cumberland Farms
Cypress Semiconductor
D.D. Bean & Sons Company
Dade Behring
DaMert Company
Danaher Controls
Dane County Public Works
Danforth Pewterers, Ltd.
Danner Shoe Manufacturing Company
DeBourgh Manufacturing Company
Delaware Solid Waste Authority
Dell Computer Corporation
Delphina's Bakery
Delta Systems, Inc.
Dependable Cleaners & Shirt Laundry, Inc.
Design Industrial Services, Inc.
Design Plastics, Inc.
Die Cut Technologies
DMD Dresser Manufacturing Division
Dole Food Company
Doug Scales Body Shop, Inc.
Dow Chemical Company
Dragon Products
DRV Energy, Inc.
Dunlop Tire Corporation
E.A. Pedersen Company
Earth Mercantile
Eaton Corporation
Ecofranchising, Inc.
Ecoprint
Ecotimber International
EcoTours of Oregon
EI du Pont de Nemours & Co.
Electro-Coatings, Inc.

Emsig Manufacturing Corporation
Engelhard
Environmental Technologies International
Epson Portland, Inc.
Erving Paper Company, Inc.
ESSROC Materials, Inc.
EuroBank
Fabe Litho
Fairview Training Center
Fantasy, Inc.
Fetzer Vineyards
Fiber Fuel International, Inc.

Fieldbrook Farms Ice Cream, Inc.
Fleischer Manufacturing, Inc.
FonTel, Inc.
Ford Microelectronics
Foseco, Inc.
Fox River Fiber
Frenchman Valley Co-op
Frog's Leap Winery
Ganton Technologies, Inc.
Gardenburger, Inc.
General Dynamics Armament Systems
General Motors Corporation
Georgia-Pacific Corporation
Gillette Company
Ginny's Printing & Copying
Global Solar
Golfsmith International, Inc.
Good Riddance, Inc.
Graham Contracting
Gridcore Systems International
H-R Industries, Inc.
Hadco Corporation
Hallmark Cards, Inc.
Hamilton County Business Center
Hanes Dye & Finishing Co.
Hass-Cal Industries, Inc.
Henningsen Foods, Inc.
Herman Miller, Inc.
Hewlett-Packard - Vancouver Site
Hews Company, Inc.
Hickory Chair Co.
Highland Industries, Inc.
Hill Production Machining
Holnam Inc.
Holy Name Hospital
Homasote Company
Horizon Technology Group - Westland
Hudson Specialty Foods
Human Powered Machines
Hurricane Compressors
Hussey Seating Company
Hyde Manufacturing Company, Inc.
IBM Corporation
IDEXX Laboratories, Inc.
Imperial Plating, Inc.
IMR Environmental Equipment, Inc.

Independent Food Processors Company

Industrial Equipment & Supplies
Inkworks Press
Inland Technology, Inc.
Interface, Inc.

Intermountain Trading Company
J&S Candles, Inc.
J. Fine Glass
Jacob North Printing
Jockey International, Inc.
Johns Manville
Johnson & Johnson
Johnson Beer Co.
Johnson Concentrates
Jones-Hamilton Co.
Just Desserts
Kaiser Permanente
Kelly-Moore/Preservative Paint Company
Kendall Plastics
Kennebec Tool & Die Company, Inc.
Kestrel Printing, Inc.
Kettle Foods
Kimiko Cards
Lafarge Corporation
Lazlo, Inc.
Lea Industries
Leeman Labs, Inc.

Lehigh Portland Cement Company
Lemforder Corporation
Lighting Components & Design, Inc.

Lindsay Manufacturing Company
Liquid Sugars, Inc.
Litton, Clifton Precision
Lockheed Martin
Longfellow Clubs, The
Loring Bank Stationers
Louis Allis Company, The
Louisiana-Pacific Corporation
Lucent Technologies, Inc.
M.J. Soffe Company
Magic Hat Brewery
Majestic Metals
Mako Marine International, Inc.
Malden Mills Industries, Inc.
Mallinckrodt, Inc.
Maple Springs Laundry

Marriott University Park Hotel
Maui Pineapple Company, Ltd.
Maxi Switch, Inc.
McCain Foods, Inc.
Measurements Group, Inc.
Mercury Marine
Mercury Recovery Services
Merix Corporation
Metal Arts Company
Metro Mobility, Inc.
Metropolis Baking Company
Miami Brewing Company
Micropyretics Heaters International, Inc.
Midwest Research Institute
Milwaukee Metropolitan Sewerage District
Minuteman Press of Berkeley
Mobile Tool International, Inc.
Motorola - Austin
Mt. Bachelor Ski and Summer Resort
National Cement Company of California, Inc.
National Jewish Center
National Linen Service
National Printing & Packaging
National Spinning Company, Inc.
Navistar International Transportation Corporation
Navistar International Transportation Corporation
Nelson Industries, Inc.
Nexstar Pharmaceuticals, Inc.
Norm Thompson Outfitters
North Shore Water Commission
Northwest Power Systems, LLC
Nuffer, Smith, Tucker, Inc.
NYCO Minerals, Inc.
O'Green Compressor Corporation
Oak Creek Water and Sewer Utility
Ohmeda
Opto Power Corporation
Oregon Cherry Growers, Inc.
Organic Cow of Vermont, The
Otter Creek Brewing, Inc.
Oxford Hotel, The
P Q Corporation
Pacific Clay Products
Pacific Coast Producers
Pacific Energy Systems, Inc.

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Pacific Gas Transmission Company
Pacific Northwest National Laboratory
Pak-Lite, Inc.
Pan American Hospital
Paraclipse
Parker Pen USA Ltd.
Passonno Paints
Pathmark Stores, Inc.
Peaceable Kingdom Press
Peacetree Environmentally Sound Paper & Printing
Peachpit Press
Peda Corporation
Penn Compression Moulding
Perfection Powder Coating, Inc.
Perko, Inc.
Phoenix Cement
Pintexs Chemical
Pinzette Glassworks
Planar America

Pohlman Foundry Company, Inc.
Polaroid Corporation
Poly Seal Industries
Power Bar, Inc.
Power Computing Corporation
Power Save
Powerhorse Lockwood Irrigation Corporation
Prime Tanning Company, Inc.
Print Room, Inc., The
PRM Energy Systems, Inc.
Production Plating, Inc.
Promega Corporation
Puerto Rico Ports Authority
Purolator Products, Inc.
Pyramid Breweries, Inc.
Quad/Graphics, Inc.
Quebecor Printing - Buffalo
RC Cement Co., Inc.
Redken Laboratories, Inc.
Regis University
Repap Wisconsin, Inc.
Republic Metals Corporation
Rhino Foods, Inc.
RMC Lonestar

Roche Vitamins & Fine Chemicals

Rochester Institute of Technology
Rocky Mountain Embossing & United States Foil Printing

SAE Circuits
Saint Barnabas Medical Center
Salerno's Kitchen Cabinets, Inc.
Samsonite Corporation
Samsung Austin Semiconductor
Sargent Controls & Aerospace
SBT Automation
Schering Plough Corporation
SEBAGO, Inc.
Sematech, Inc.
Serigraph, Inc.
Sheraton New York Hotel & Towers
Siemens Energy & Automation, Inc.
Skills, Inc.
Slater Companies, The
Snap-On Tools Company
Solar Turbines
Southdown, Inc.
Southwire Company - Utah Plant
Spectrum Printing
SSI Technologies, Inc.
Stinson Seafood Company
Stonyfield Farm Yogurt, Inc.
Storey Framing
Stull Technologies
SUCRON, Inc.
Sulzer Orthopedics, Inc.
Sulzer Pumps, Inc.
Sun-Kist Dry Cleaners
Surface Design and Technology
Sutter Home Winery, Inc.
Sweeney Furniture
Synthech Products
T. A. CAID Industries
Tacoma Goodwill Industries
Temp Control Mechanical Service
Tokyo Electron America, Inc.
Total Petroleum Commerce Refinery
Total Reclaim, Inc.
Tran Tec Corporation
Tri Valley Growers
Trumpf, Inc.
TRW, Inc.
Tube Products Corporation
Twin Rivers Technologies
U.S. Olympic Committee
U.S. Postal Service, District of Maine

U.S. Postal Service, South Florida District
U.S. West, Inc.
University of Idaho
Uno Restaurants, Inc.

Valdese Manufacturing Company
Valleylab, Inc.
Vermont Butter and Cheese Company
Victory Farms, Inc.
Virginia Bakery
Virkler Company
Vital Vittles
Vogel West, Inc.
Warner Bros. Publications
Weaver Potato Chip Company, Inc.
Weber Printing, Inc.
Wellco Ro. Search Inc.
West Bend Company, The
West Press
Westin La Paloma, The
Westin, Inc.
Westinghouse Motor Company
Weyerhaeuser Company
Wheelskins, Inc.

Whittier Creamery Company, Inc.
Willamette Valley Vineyards
Window Wares, Inc.
World Envirotech Services
World Wood Company
Worldwide Clairol
Wynkoop Brewing Company
Zap Power Systems
Zenith-Goldline Pharmaceuticals
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Climate Wise Partners by State

ST	Company	Field20
AR		
	PRM Energy Systems, Inc.	Hot Springs, AR
AZ		
	Arizona Lithographers	Tucson, AZ
	Arizona Portland Cement Company	Rillito, AZ
	Delta Systems, Inc.	Tucson, AZ
	Fabe Litho	Tucson, AZ
	Global Solar	Tucson, AZ
	Marriott University Park Hotel	Tucson, AZ
	Maxi Switch, Inc.	Tucson, AZ
	Opto Power Corporation	Tucson, AZ
	Perfection Powder Coating, Inc.	Tucson, AZ
	Phoenix Cement	Clarkdale, AZ
	Print Room, Inc., The	Tucson, AZ
	Sargent Controls & Aerospace	Tucson, AZ
	Spectrum Printing	Tucson, AZ
	T. A. CAID Industries	Tucson, AZ
	West Press	Tucson, AZ
	Westin La Paloma, The	Tucson, AZ
CA		
	Acme Bread Company	Berkeley, CA
	Advance Heli-Welders & Manufacturing Company, Inc.	Berkeley, CA
	Allergan, Inc.	Irvine, CA
	American Soil Products	Berkeley, CA
	Andros Incorporated	Berkeley, CA
	Apollo Printing	Berkeley, CA
	Bayview Technology	San Carlos, CA
	Beaulieu Vineyard	Rutherford, CA
	Beringer Vineyards	St. Helena, CA
	Berkeley Mills East West Furniture Design	Berkeley, CA
	Buena Vista Winery, Inc.	Sonoma, CA
	Calaveras Cement Company	Monolith, CA
	California Portland Cement Company	Glendora, CA
	Cheese Cake City, Inc.	Berkeley, CA
	Clearflow Valves	Berkeley, CA
	DaMert Company	Berkeley, CA
	Dole Food Company	Westlake Village, CA
	Ecotimber International	Berkeley, CA
	Electro-Coatings, Inc.	Berkeley, CA
	Fantasy, Inc.	Berkeley, CA
	Fetzer Vineyards	Hopeland, CA
	Frog's Leap Winery	Rutherford, CA
	Gridcore Systems International	Long Beach, CA

Hass-Cal Industries, Inc.	Carpinteria, CA
Hill Production Machining	Berkeley, CA
Inkworks Press	Berkeley, CA
Intermountain Trading Company	Berkeley, CA
J&S Candles, Inc.	Berkeley, CA
J. Fine Glass	Berkeley, CA
Just Desserts	San Francisco, CA
Kaiser Permanente	Berkeley, CA
Kimiko Cards	Berkeley, CA
Liquid Sugars, Inc.	Emeryville, CA
Louisiana-Pacific Corporation	Samoa, CA
Mercury Recovery Services	Pomona, CA
Metropolis Baking Company	Berkeley, CA
Minuteman Press of Berkeley	Berkeley, CA
National Cement Company of California, Inc.	Lebec, CA
Nuffer, Smith, Tucker, Inc.	San Diego, CA
P Q Corporation	Berkeley, CA
Pacific Clay Products	Lake Elsinore, CA
Pacific Coast Producers	Lodi, CA
Peaceable Kingdom Press	Berkeley, CA
Peachpit Press	Berkeley, CA
Peda Corporation	Palo Alto, CA
Pinzette Glassworks	Berkeley, CA
Poly Seal Industries	Berkeley, CA
Power Bar, Inc.	Berkeley, CA
Pyramid Breweries, Inc.	Berkeley, CA
RMC Lonestar	Davenport, CA
Storey Framing	Berkeley, CA
Sutter Home Winery, Inc.	St. Helena, CA
Sweeney Furniture	Berkeley, CA
Tri Valley Growers	Modesto, CA
Virginia Bakery	Berkeley, CA
Vital Vittles	Berkeley, CA
Wheelskins, Inc.	Berkeley, CA
Zap Power Systems	Sebastopol, CA

CO

ABC Wholesale Roofing	Denver, CO
Asarco, Inc. - Globe Plant	Denver, CO
Association of American Railroads	Pueblo, CO
Ball Packaging Corporation	Broomfield, CO
Central Products Company - Brighton	Brighton, CO
CF&I Steel, L.P.	Pueblo, CO
Colorado School of Mines	Golden, CO
Colorado's Ocean Journey	Denver, CO
Coors Brewing Company	Golden, CO
DeBourgh Manufacturing Company	LaJunta, CO

	Dependable Cleaners & Shirt Laundry, Inc.	Denver, CO
	Die Cut Technologies	Denver, CO
	Ford Microelectronics	Colorado Springs, CO
	Lockheed Martin	Littleton, CO
	Majestic Metals	Denver, CO
	Metro Mobility, Inc.	Denver, CO
	Mobile Tool International, Inc.	Westminster, CO
	National Jewish Center	Denver, CO
	National Printing & Packaging	Denver, CO
	Nexstar Pharmaceuticals, Inc.	Boulder, CO
	Oxford Hotel, The	Denver, CO
	Regis University	Denver, CO
	Rocky Mountain Embossing & United States Foil Printing	Denver, CO
	SAE Circuits	Boulder, CO
	Samsonite Corporation	Denver, CO
	Total Petroleum Commerce Refinery	Commerce City, CO
	U.S. Olympic Committee	Colorado Springs, CO
	U.S. West, Inc.	Denver, CO
	Valleylab, Inc.	Boulder, CO
	Wynkoop Brewing Company	Denver, CO
CT		
	Branson Ultrasonics Corporation	Danbury, CT
	Trumpf, Inc.	Farmington, CT
	Worldwide Clairol	Stamford, CT
DC		
	Burrito Brothers, Inc.	Washington, DC
	Dow Chemical Company	Washington, DC
	Solar Turbines	Washington, DC
DE		
	Delaware Solid Waste Authority	Dover, DE
	El du Pont de Nemours & Co.	Wilmington, DE
FL		
	Adapto Storage Products	Hialeah, FL
	Apache Products Company	Miami, FL
	Ashland Chemical, Inc.	Miami, FL
	Blumenthal Export, Inc.	Opa Locka, FL
	Dade Behring	Miami, FL
	Engelhard	Miami, FL
	EuroBank	Coral Gables, FL
	Imperial Plating, Inc.	Opa Locka, FL
	IMR Environmental Equipment, Inc.	St. Petersburg, FL

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	Industrial Equipment & Supplies	Miami, FL
	Kendall Plastics	Miami, FL
	Lighting Components & Design, Inc.	Deerfield Beach, FL
	Mako Marine International, Inc.	Miami, FL
	Miami Brewing Company	Medley, FL
	Pan American Hospital	Miami, FL
	Perko, Inc.	Miami, FL
	Pintexs Chemical	Opa-Locka, FL
	Republic Metals Corporation	Opa-Locka, FL
	Surface Design and Technology	Hialeah, FL
	U.S. Postal Service, South Florida District	Pembroke Pines, FL
	Warner Bros. Publications	Miami, FL
	Zenith-Goldline Pharmaceuticals	Miami, FL
GA		
	Fiber Fuel International, Inc.	Savannah, GA
	Georgia-Pacific Corporation	Atlanta, GA
	Interface, Inc.	Kennesaw, GA
HI		
	Maui Pineapple Company, Ltd.	Kahului, HI
ID		
	University of Idaho	Moscow, ID
IL		
	Baxter International	Deerfield, IL
	Navistar International Transportation Corporation	Chicago, IL
IN		
	Hurricane Compressors	Franklin, IN
KS		
	Ash Grove Cement Company	Overland Park, KS
KY		
	Redken Laboratories, Inc.	Florence, KY
LA		
	SUCRON, Inc.	Clinton, LA
MA		
	Advanced Cast Products/Belcher Corp.	Easton, MA
	Barbour Plastics, Inc.	Brockton, MA
	Boston Retail Products	Medford, MA
	Capitol Circuits Corporation	Boston, MA
	Central Metal Finishing, Inc.	No. Andover, MA
	Cranston Print Works	Webster, MA
	Cumberland Farms	Canton, MA
	Erving Paper Company, Inc.	Erving, MA
	Gillette Company	Boston, MA
	Graham Contracting	Wayland, MA

	Hyde Manufacturing Company, Inc.	Southbridge, MA
	Leeman Labs, Inc.	Lowell, MA
	Longfellow Clubs, The	Wayland, MA
	Malden Mills Industries, Inc.	Lawrence, MA
	Polaroid Corporation	Waltham, MA
	Twin Rivers Technologies	Quincy, MA
	Uno Restaurants, Inc.	W. Roxbury, MA
	Whittier Creamery Company, Inc.	Shrewsbury, MA
MD		
	Ecoprint	Silver Spring, MD
ME		
	ACORN	Lewiston, ME
	Brewer Automotive Components	Brewer, ME
	Dragon Products	Portland, ME
	Hews Company, Inc.	South Portland, ME
	Hussey Seating Company	North Berwick, ME
	IDEXX Laboratories, Inc.	Westbrook, ME
	Johns Manville	Portland, ME
	Kennebec Tool & Die Company, Inc.	Augusta, ME
	Lemforder Corporation	Brewer, ME
	Loring Bank Stationers	Yarmouth, ME
	SEBAGO, Inc.	Gorham, ME
	Stinson Seafood Company	Bath, ME
	U.S. Postal Service, District of Maine	Portland, ME
MI		
	General Motors Corporation	Detroit, MI
	Herman Miller, Inc.	Zeeland, MI
	Holnam Inc.	Dundee, MI
	Horizon Technology Group - Westland	Westland, MI
MN		
	3M Company	St. Paul, MN
	Aveda Corporation	Minneapolis, MN
MO		
	Anheuser-Busch Companies	St. Louis, MO
	Hallmark Cards, Inc.	Kansas City, MO
	Midwest Research Institute	Kansas City, MO
NC		
	Ajinomoto USA, Inc.	Raleigh, NC
	Austin Quality Foods Inc.	Cary, NC
	Azdel, Inc.	Shelby, NC
	Baxter Healthcare Corporation	Marion, NC
	Cargill, Inc.	Raleigh, NC
	Cross Creek Apparel, Inc.	Mount Airy, NC

	Danaher Controls	Elizabethtown, NC
	Eaton Corporation	Selma, NC
	Hanes Dye & Finishing Co.	Winston-Salem, NC
	Hickory Chair Co.	Hickory, NC
	Highland Industries, Inc.	Kernersville, NC
	Johnson Beer Co.	Charlotte, NC
	Lea Industries	Waynesville, NC
	Litton, Clifton Precision	Murphy, NC
	M.J. Soffe Company	Fayetteville, NC
	Mallinckrodt, Inc.	Raleigh, NC
	Maple Springs Laundry	Hickory, NC
	Measurements Group, Inc.	Wendell, NC
	National Spinning Company, Inc.	Washington, NC
	Pak-Lite, Inc.	Mebane, NC
	Siemens Energy & Automation, Inc.	Raleigh, NC
	Valdese Manufacturing Company	Valdese, NC
	Virkler Company	Charlotte, NC
	Wellco Ro. Search Inc.	Waynesville, NC
	World Wood Company	Cove City, NC
NE		
	Abe Krasne Home Furnishings	Fremont, NE
	Behlen Manufacturing Company	Columbus, NE
	Broyhill Company	Dakota City, NE
	Buffalo County	Kearney, NE
	Central Confinement Service, Ltd.	Columbus, NE
	Design Plastics, Inc.	Omaha, NE
	E.A. Pedersen Company	Omaha, NE
	Fleischer Manufacturing, Inc.	Columbus, NE
	FonTel, Inc.	Aurora, NE
	Frenchman Valley Co-op	Imperial, NE
	Henningsen Foods, Inc.	Omaha, NE
	Hudson Specialty Foods	Columbus, NE
	Jacob North Printing	Lincoln, NE
	Lazlo, Inc.	Lincoln, NE
	Lindsay Manufacturing Company	Lindsay, NE
	Paraclipse	Columbus, NE
	Powerhorse Lockwood Irrigation Corporation	Gering, NE
	Sun-Kist Dry Cleaners	Lincoln, NE
	Tran Tec Corporation	Columbus, NE
	Vogel West, Inc.	Omaha, NE
	Weaver Potato Chip Company, Inc.	Lincoln, NE
	Weber Printing, Inc.	Lincoln, NE
	Westin, Inc.	Omaha, NE

	Window Wares, Inc.	Omaha, NE
NH		
	Advanced Circuit Technology	Nasua, NH
	Bagel Works, Inc.	Keene, NH
	Cirtronics	Milford, NH
	D.D. Bean & Sons Company	Jaffrey, NH
	Hadco Corporation	Salem, NH
	Prime Tanning Company, Inc.	Rochester, NH
	Stonyfield Farm Yogurt, Inc.	Londonderry, NH
NJ		
	AT&T	Basking Ridge, NJ
	Bristol-Myers Squibb Company	Princeton, NJ
	Captive Plastics, Inc.	Piscataway, NJ
	Cosmair, Inc. - Clark Facility	Clark, NJ
	Cosmair, Inc. - Somerset Facility	Somerset, NJ
	Holy Name Hospital	Teaneck, NJ
	Homasote Company	West Trenton, NJ
	Johnson & Johnson	New Brunswick, NJ
	Lucent Technologies, Inc.	Morristown, NJ
	Pathmark Stores, Inc.	Woodbridge, NJ
	Roche Vitamins & Fine Chemicals	Belvidere, NJ
	Saint Barnabas Medical Center	Livingston, NJ
	Salerno's Kitchen Cabinets, Inc.	Saddle Brook, NJ
	Schering Plough Corporation	Kenilworth, NJ
	Stull Technologies	Randolph, NJ
NY		
	Anitec, International Paper	Binghamton, NY
	Atlas Copco Comptec, Inc.	Voorheesville, NY
	BP America Inc.	New York, NY
	Dunlop Tire Corporation	Buffalo, NY
	Ecofranchising, Inc.	Mamaroneck, NY
	Emsig Manufacturing Corporation	Hudson, NY
	Fieldbrook Farms Ice Cream, Inc.	Dunkirk, NY
	Good Riddance, Inc.	Alplaus, NY
	IBM Corporation	Somers, NY
	Metal Arts Company	Geneva, NY
	NYCO Minerals, Inc.	Willsboro, NY
	Passonno Paints	Watervliet, NY
	Pohlman Foundry Company, Inc.	Buffalo, NY
	Quebecor Printing - Buffalo	Depew, NY

	Rochester Institute of Technology	Rochester, NY
	Sheraton New York Hotel & Towers	New York, NY
OH		
	Crown Battery Manufacturing Company	Fremont, OH
	Foseco, Inc.	Cleveland, OH
	Hamilton County Business Center	Cincinnati, OH
	Jones-Hamilton Co.	Walbridge, OH
	Micropyretics Heaters International, Inc.	Cincinnati, OH
	Synthech Products	Toledo, OH
	TRW, Inc.	Lyndhurst, OH
	Tube Products Corporation	Troy, OH
	Victory Farms, Inc.	Blacklick, OH
OK		
	DRV Energy, Inc.	Oklahoma City, OK
OR		
	Ashforth Pacific	Portland, OR
	Cascade General, Inc.	Portland, OR
	Clermont, Inc.	Hillsboro, OR
	Columbia Steel Products Company	Portland, OR
	Danner Shoe Manufacturing Company	Portland, OR
	Delphina's Bakery	Portland, OR
	Earth Mercantile	Portland, OR
	EcoTours of Oregon	Portland, OR
	Environmental Technologies International	Eugene, OR
	Epson Portland, Inc.	Hillsboro, OR
	Fairview Training Center	Salem, OR
	Gardenburger, Inc.	Portland, OR
	Human Powered Machines	Eugene, OR
	Kettle Foods	Salem, OR
	Merix Corporation	Forest Grove, OR
	Mt. Bachelor Ski and Summer Resort	Bend, OR
	Norm Thompson Outfitters	Hillsboro, OR
	Northwest Power Systems, LLC	Bend, OR
	O'Green Compressor Corporation	Eugene, OR
	Oregon Cherry Growers, Inc.	Salem, OR
	Pacific Energy Systems, Inc.	Portland, OR
	Pacific Gas Transmission Company	Portland, OR
	Peacetree Environmentally Sound Paper & Printing	Portland, OR
	Planar America	Beaverton, OR
	Power Save	Cottage Grove, OR

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	Sulzer Pumps, Inc.	Portland, OR
	Temp Control Mechanical Service	Portland, OR
	Willamette Valley Vineyards	Turner, OR
	World Envirotech Services	Hillsboro, OR
PA		
	Bethlehem Steel Corporation	Bethlehem, PA
	Concord Beverage Company	Concordville, PA
	DMD Dresser Manufacturing Division	Bradford, PA
	ESSROC Materials, Inc.	Nazareth, PA
	Lehigh Portland Cement Company	Allentown, PA
	Penn Compression Moulding	Irwin, PA
	RC Cement Co., Inc.	Bethelhem, PA
PR		
	Puerto Rico Ports Authority	Guaynabo, PR
RI		
	Slater Companies, The	Pawtucket, RI
TX		
	3M Austin Center	Austin, TX
	Advanced Micro Devices, Inc.	Austin, TX
	Air Products & Chemicals	Austin, TX
	Apple Computer, Inc. - Austin	Austin, TX
	Applied Materials, Inc. - Austin	Austin, TX
	Austin Commercial, Inc.	Austin, TX
	Capitol Aggregates Ltd.	San Antonio, TX
	Cypress Semiconductor	Roundrock, TX
	Dell Computer Corporation	Round Rock, TX
	Doug Scales Body Shop, Inc.	Austin, TX
	Ginny's Printing & Copying	Austin, TX
	Golfsmith International, Inc.	Austin, TX
	H-R Industries, Inc.	Richardson, TX
	Kestrel Printing, Inc.	Austin, TX
	Motorola - Austin	Austin, TX
	National Linen Service	Austin, TX
	Power Computing Corporation	Round Rock, TX
	Samsung Austin Semiconductor	Austin, TX
	SBT Automation	Boerne, TX
	Sematech, Inc.	Austin, TX
	Southdown, Inc.	Houston, TX
	Sulzer Orthopedics, Inc.	Austin, TX
	Tokyo Electron America, Inc.	Austin, TX
	Westinghouse Motor Company	Round Rock, TX
UT		

	Purolator Products, Inc.	Salt Lake City, UT
	Southwire Company - Utah Plant	West Jordan, UT
VA		
	Lafarge Corporation	Reston, VA
VT		
	Autumn Harp, Inc.	Bristol, VT
	Blodgett Oven Company	Burlington, VT
	Catamount Brewing Company	White River Junction, VT
	Conant Custom Brass, Inc.	Burlington, VT
	Danforth Pewterers, Ltd.	Middlebury, VT
	General Dynamics Armament Systems	Burlington, VT
	Magic Hat Brewery	S. Burlington, VT
	Organic Cow of Vermont, The	Tunbridge, VT
	Otter Creek Brewing, Inc.	Middlebury, VT
	Rhino Foods, Inc.	Burlington, VT
	Vermont Butter and Cheese Company	Websterville, VT
WA		
	Ace Galvanizing	Seattle, WA
	Blaser Die Casting	Seattle, WA
	Boeing Company, The	Seattle, WA
	Design Industrial Services, Inc.	Kennewick, WA
	Hewlett-Packard - Vancouver Site	Vancouver, WA
	Independent Food Processors Company	Yakima, WA
	Inland Technology, Inc.	Tacoma, WA
	Johnson Concentrates	Sunnyside, WA
	Kelly-Moore/Preservative Paint Company	Seattle, WA
	McCain Foods, Inc.	Othello, WA
	Pacific Northwest National Laboratory	Richland, WA
	Production Plating, Inc.	Mukilteo, WA
	Skills, Inc.	Seattle, WA
	Tacoma Goodwill Industries	Tacoma, WA
	Total Reclaim, Inc.	Seattle, WA
	Weyerhaeuser Company	Tacoma, WA
WI		
	American Cat Emporium & Wood Products	New Lisbon, WI
	Barkow Manufacturing Company, Inc.	Milwaukee, WI
	Briggs & Stratton Corporation	Wauwatosa, WI
	Bureau of Correctional Enterprises	Madison, WI
	Dane County Public Works	Madison, WI
	Fox River Fiber	DePere, WI
	Ganton Technologies, Inc.	Sturtevant, WI

Jockey International, Inc.	Kenosha, WI
Louis Allis Company, The	Milwaukee, WI
Mercury Marine	Fond du Lac, WI
Milwaukee Metropolitan Sewerage District	Oak Creek, WI
Navistar International Transportation Corporation	Waukesha, WI
Nelson Industries, Inc.	Stoughton, WI
North Shore Water Commission	Glendale, WI
Oak Creek Water and Sewer Utility	Oak Creek, WI
Ohmeda	Madison, WI
Parker Pen USA Ltd.	Janesville, WI
Promega Corporation	Madison, WI
Quad/Graphics, Inc.	Pewaukee, WI
Repap Wisconsin, Inc.	Kimberly, WI
Serigraph, Inc.	West Bend, WI
Snap-On Tools Company	Kenosha, WI
SSI Technologies, Inc.	Janesville, WI
West Bend Company, The	West Bend, WI

Q15.2 Please document the statement that "Companies have submitted Action Plans detailing more than 700 emissions reductions actions that they estimate will reduce greenhouse gas emissions by more than 5 million metric tons of carbon equivalent by the year 2000. In the process they expect to save more than $300 million."

A15.2 Attached is an action plan spreadsheet listing almost 1000 voluntary emission reduction actions as well as a paper that outlines some explicit examples of individual company actions and some of the associated savings.

Climate Wise Company Actions

Company	Action Number	Action Group	Main Action	Activity Description	IAC Code
3M Austin Center	1		HVAC		
3M Austin Center	1		Lighting		
3M Austin Center	2		Envelope		
3M Austin Center	3		Community/Supplier Outreach/Education		
3M Austin Center	4		Process Improvement		
3M Austin Center	5		Cogeneration		
3M Austin Center	6		Transportation		
3M Austin Center	7		Recycling		
3M Austin Center	8		Community/Supplier Outreach/Education		
3M Austin Center	9		Energy Audit		
3M Austin Center	10		Water Use		
3M Austin Center	11		Water Use		
3M Austin Center	12		Water Use		
3M Austin Center	13		Water Use		
3M Austin Center	14		Compressed Air		
3M Austin Center	15		HVAC		
3M Austin Center	16		Envelope		
3M Austin Center	17		Alternative Energy		
3M Austin Center	18		Compressed Air		
3M Austin Center	18		Steam System		
3M Austin Center	19		HVAC		
3M Austin Center	20		Envelope		
Allergan, Inc.			Process Heating	Optimizing	
Allergan, Inc.			Steam System	Steam Traps	
Allergan, Inc.			Lighting		

AP Actions

Allergan, Inc.			Office		
Allergan, Inc.			Process Cooling		
Allergan, Inc.			Boiler	Optimization	
Allergan, Inc.			Water Use		
Allergan, Inc.			Water Use		
Allergan, Inc.			Process Improvement		
Allergan, Inc.			Process Cooling	Cooling Tower - Free cooling	
Allergan, Inc.			Steam System	Insulation	
Allergan, Inc.			Motor Systems and VFD		
Allergan, Inc.			Motor Systems and VFD		
Allergan, Inc.			Recycling		
Allergan, Inc.			Recycling		
Allergan, Inc.			Water Use		
Allergan, Inc.			Lighting		
Allergan, Inc.			Process Improvement		
Allergan, Inc.			Insulation		
Arizona Portland Cement Co.	1		Process Heating		
Arizona Portland Cement Co.	2		Lighting		
Arizona Portland Cement Co.	3		Compressed Air		
Arizona Portland Cement Co.	4		Process Improvement		
Arizona Portland Cement Co.	5		Process Improvement		
Arizona Portland Cement Co.	6		Process Improvement		
Arizona Portland Cement Co.	7		Process Improvement		
Arizona Portland Cement Co.	8		Fuel Switching		
Arizona Portland Cement Co.	9		Transportation		
Arizona Portland Cement Co.	10		Process Improvement		
Arizona Portland Cement Co.	11		Motor Systems and VFD		
Asarco	1		Motor Systems and VFD		
Asarco	2		Motor Systems and VFD		
Asarco	3		Lighting		
Asarco	4		Process Improvement		

AP Actions

Asarco	5		Compressed Air	Upgarade	
Asarco	6		PP		
Ashland Chemical, Inc.		Corporate ,	Community/Supplier Outreach/Education	Community Outreach	5221
Ashland Chemical, Inc.		Corporate ,	PP	Employee Training	5233
Ashland Chemical, Inc.		Corporate ,	Lighting	Other Voluntary Commitments	5236
Ashland Chemical, Inc.		Waste Elir	PP	Waste Stream Contamination-Miscellaneous	3123
Ashland Chemical, Inc.		Other	PP	None	
Ashland Chemical, Inc.		Other	Process Improvement	None	
Ashland Chemical, Inc.		Corporate ,	Community/Supplier Outreach/Education	Community Outreach	5221
Ashland Chemical, Inc.		Waste Elir	PP	General-Removal of Contaminants	3312
Ashland Chemical, Inc.		Building an	Office	Energy Efficient Equipment	5110
Ashland Chemical, Inc.		Waste Elir	Recycling	Other Materials-General	3531
Ashland Chemical, Inc.		Corporate ,	Community/Supplier Outreach/Education	Employee Training	5233
Ashland Chemical, Inc.		Waste Elir	PP	Waste Stream Contamination-Miscellaneous	3123
Ashland Chemical, Inc.		Waste Elir	Recycling	Other Materials-General	3531
Ashland Chemical, Inc.		Building an	HVAC	Space Conditioning-Hardware-Heating/Cooling	2723
Ashland Chemical, Inc.		Waste Elir	PP	Spillage-Operations	3721
Ashland Chemical, Inc.		Waste Elir	PP	Waste Stream Contamination-Miscellaneous	3123
Ashland Chemical, Inc.		Forestry	Forest Preservation/ Tree Planting	Tree Planting	5330
Ashland Chemical, Inc.		Other	Process Improvement	None	

AP Actions

Ashland Chemical, Inc.		Industrial E	PP	General-Process Specific Upgrades	3213
Ashland Chemical, Inc.		Waste Elim	PP	Procedures-Miscellaneous	3119
Ashland Chemical, Inc.		Other	PP	None	
AT&T		Transporta	Transportation	General	5520
AT&T		Corporate .	Energy Management Operations	Performance Targets	5237
AT&T		Building an	Office	Energy Efficient Equipment	5110
AT&T		Corporate .	PP	General	5234
Bayview Technology	1		Office		
Behlen Manufacturing Company		Industrial E	Boiler	Boilers-Hardware	2122
Behlen Manufacturing Company		Waste Elim	PP	Solvents-Solvent Recovery	3814
Behlen Manufacturing Company		Building an	Envelope	Building Envelope-Infiltration	2741
Behlen Manufacturing Company		Industrial E	Motor Systems and VFD	Air Compressors-Operations	2421
Behlen Manufacturing Company		Waste Elim	PP	Solvents- Use Reduction	3811
Behlen Manufacturing Company		Building an	Lighting	Hardware	2714
Behlen Manufacturing Company		Industrial E	Process Improvement	General-Painting Operations	3212
Behlen Manufacturing Company		Waste Elim	PP	General-Sludge Maintenance	3611

AP Actions

Behlen Manufacturing Company		Waste Elin	Recycling	Liquid Waste-Miscellaneous	3514
Behlen Manufacturing Company		Building an	Lighting	Hardware	2714
Behlen Manufacturing Company		Waste Elin	PP	Solvents-Material Replacement	3813
Bristol-Myers Squibb Company			HVAC		
Bristol-Myers Squibb Company		Corporate	Envelope	General	5234
Bristol-Myers Squibb Company			HVAC		
Bristol-Myers Squibb Company		Building an	Lighting	Hardware	2714
Bristol-Myers Squibb Company		Industrial E	Energy Management Operations	Demand Management-Miscellaneous	2312
Bristol-Myers Squibb Company		Building an	Lighting	Operation	2712
Bristol-Myers Squibb Company		Industrial E	Steam System	Steam-Condensate	2212
Bristol-Myers Squibb Company			Boiler	Phase out	
Bristol-Myers Squibb Company		Building an	HVAC	Space Conditioning-Hardware-Heating/Cooling	2723
Bristol-Myers Squibb Company		Building an	Office	Energy Efficient Equipment	5110
Bristol-Myers Squibb Company		Corporate	Energy Tracking/Reporting	Teams	5212
Bristol-Myers Squibb Company		Building an	Lighting	Level	2711
Bristol-Myers Squibb Company		Industrial E	Cogeneration	Cogeneration-General	2341
Bristol-Myers Squibb Company		Building an	Lighting	Hardware	2714
Bristol-Myers Squibb Company		Industrial E	Energy Management Operations	Transmission-Transformers	2351
Bristol-Myers Squibb Company			HVAC		
Bristol-Myers Squibb Company		Industrial E	Motor Systems and VFD	Air Compressors-Hardware	2422

AP Actions

Bristol-Myers Squibb Company		Industrial E	Process Cooling	Cooling-Cooling Towers	2261
Bristol-Myers Squibb Company		Building an	Lighting	Controls	2713
Bristol-Myers Squibb Company		Industrial E	Steam System	Steam- Traps	2211
Bristol-Myers Squibb Company		Building an	HVAC	Space Conditioning-Controls	2713
Bristol-Myers Squibb Company		Industrial E	Process Cooling	Cooling-Chillers and Refrigeration	2262
Bristol-Myers Squibb Company			Energy Management Operations		
Bristol-Myers Squibb Company		Industrial E	Process Cooling	Cooling-Chillers and Refrigeration	2262
Bristol-Myers Squibb Company		Industrial E	Cogeneration	Cogeneration-General	2341
Bristol-Myers Squibb Company		Building an	HVAC	Ventilation-General	2731
Bristol-Myers Squibb Company		Building an	HVAC	Space Conditioning-Miscellaneous	2728
Bristol-Myers Squibb Company			Process Improvement		
Calaveras Cement Co.	1		Process Improvement		
Calif. Portland Cement co. - Colton	1		Process Heating		
Calif. Portland Cement co. - Colton	2		HVAC		
Calif. Portland Cement co. - Colton	3		Compressed Air		
Calif. Portland Cement co. - Colton	4		Process Improvement		
Calif. Portland Cement co. - Colton	5		Process Improvement		
Calif. Portland Cement co. - Colton	6		Process Improvement		
Calif. Portland Cement co. - Colton	7		Fuel Switching		
Calif. Portland Cement co. - Colton	8		Process Improvement		
Calif. Portland Cement co. - Mojave	1		Fuel Switching		
Calif. Portland Cement co. - Mojave	2		Process Improvement		
Calif. Portland Cement co. - Mojave	3		Process Heating		

Calif. Portland Cement co. - Mojave	4		Process Improvement		
Calif. Portland Cement co. - Mojave	5		Compressed Air		
Calif. Portland Cement co. - Mojave	6		Process Improvement		
Cargill, Inc.			Energy Management Operations		
Cargill, Inc.			Steam System	Steam Traps	
Cargill, Inc.			Water Use		
Cargill, Inc.			PP		
Cargill, Inc.			Energy Management Operations		
Cargill, Inc.			Motor Systems and VFD		
Cargill, Inc.			Energy Audit		
Cargill, Inc.			Boiler	Upgrade	
Cargill, Inc.			Process Improvement		
Cargill, Inc.			Boiler	Insulation	
Central Products Company - Brighton		Industrial E	Heat Exchanger/ Recovery	Heat Recovery-Heat Recovery From Specific Equipment	2243
Central Products Company - Brighton		Industrial E	Process Improvement	Demand Management-Miscellaneous	2312
Central Products Company - Brighton		Building an	Office	Energy Efficient Equipment	5110
Central Products Company - Brighton		Building an	Envelope	Building Envelope-Infiltration	2741
Central Products Company - Brighton		Building an	HVAC	Space Conditioneing-Controls	2726
Central Products Company - Brighton		Building an	Lighting	Hardware	2714

AP Actions

Central Products Company - Brighton		Industrial E	Process Cooling	Cooling- Chillers and Refrigeration	2262
Central Products Company - Brighton		Industrial E	Steam System	Steam- Traps	2211
Central Products Company - Brighton		Industrial E	Steam System	Steam- Leaks and Insulation	2213
Central Products Company - Brighton		Industrial E	Heat Exchanger/ Recovery	Heat Recovery- Heat Recovery from Specific Equipment	2243
Central Products Company - Brighton		Industrial E	Motor Systems and VFD	Air Compressors- Operations	2421
Central Products Company - Brighton		Industrial E	Motor Systems and VFD	Motors- Hardware	2412
Central Products Company - Brighton		Building an	Lighting	Controls	2713
Central Products Company - Brighton		Waste Elim	Heat Exchanger/ Recovery	Solvents- Solvent Recovery	3814
Central Products Company - Brighton		Industrial E	Process Improvement	General- Painting Operations	3212
Central Products Company - Brighton		Industrial E	Process Heating	General- Painting Operations	3212
Central Products Company - Brighton		Industrial E	Heat Exchanger/ Recovery	Heat Recovery- Heat Recovery From Specific Equipment	2243
Central Products Company - Brighton		Industrial E	Heat Exchanger/ Recovery	Heat Recovery- Heat Recovery From Specific Equipment	2243
Central Products Company - Brighton		Industrial E	Process Heating	Furnaces, Ovens, and Directly Fired Operations- Operations	2111
CF&I	1		Lighting		
CF&I	2		Lighting		
CF&I	3		Process Heating	Upgrade	
CF&I	4		Process Heating	Upgrade	
CF&I	5		PP		
CF&I	6		PP		

AP Actions

CF&I	7		PP		
CF&I	8		Recycling		
CF&I	9		Boiler	Upgrade	
CF&I Steel, L.P.		Industrial E	Process Cooling	Cooling-Chillers and Refrigeration	2262
CF&I Steel, L.P.		Industrial E	Energy Management Operations	Administrative-Utility Costs	2811
CF&I Steel, L.P.		Waste Elim	Water Use	General- Water Quality	3413
Colorado School of Mines	1		Steam System	Steam Trap	
Colorado School of Mines	2		Steam System	Audit	
Colorado School of Mines	3		Lighting		
Colorado School of Mines	4		Compressed Air	Maintencence program	
Colorado School of Mines	5		HVAC		
Colorado School of Mines	6		Motor Systems and VFD		
Colorado School of Mines	7		Envelope		
Colorado School of Mines	8		Heat Exchanger/ Recovery		
Colorado School of Mines	9		Boiler	Upgade	
Colorado School of Mines	10		Energy Management Operations		
Conant Custom Brass, Inc.		Corporate .	Energy Audit	Audit	5231
Conant Custom Brass, Inc.		Waste Elim	Recycling	Solid Waste-Metals	3523
Conant Custom Brass, Inc.		Building an	Lighting	Operation	2712
Conant Custom Brass, Inc.		Building an	HVAC	Space Conditioning-Operation	2722
Conant Custom Brass, Inc.		Waste Elim	Recycling	Liquid Waste-Miscellaneous	3514
Conant Custom Brass, Inc.		Waste Elim	Recycling	Other Materials-General	3531
Conant Custom Brass, Inc.		Waste Elim	Recycling	Other Materials-General	3531
Conant Custom Brass, Inc.		Waste Elim	PP	Solvents-Solvent Recovery	3814
Conant Custom Brass, Inc.		Waste Elim	PP	Solvents-Emission Reduction	3812

Conant Custom Brass, Inc.		Waste Elim	Water Use	General- Close Cycle Water Use	3411
Conant Custom Brass, Inc.		Waste Elim	PP	Solvents-Material Replacement	3813
Conant Custom Brass, Inc.		Waste Elim	Water Use	General- Close Cycle Water Use	3411
Conant Custom Brass, Inc.		Industrial E	Process Heating	Heating-Operation	2221
Conant Custom Brass, Inc.		Building an	Lighting	Controls	2713
Conant Custom Brass, Inc.		Building an	HVAC	Space Conditioning-Controls	2726
Conant Custom Brass, Inc.		Building an	Envelope	Building Envelope-Infiltration	2741
Conant Custom Brass, Inc.		Building an	Lighting	Hardware	2714
Conant Custom Brass, Inc.		Industrial E	Motor Systems and VFD	Motors-Hardware	2412
Conant Custom Brass, Inc.		Industrial E	Energy Management Operations	Administrative-Utility Costs	2811
Concord Beverage Company		Waste Elim	Recycling	Other Materials-General	3531
Concord Beverage Company		Waste Elim	Recycling	Other Materials-General	3531
Concord Beverage Company		Corporate .	Energy Management Operations	Tracking Activities	5242
Concord Beverage Company		Waste Elim	Recycling	Liquid Waste-Miscellaneous	3514
Coors Brewing Company		Corporate .	PP	Other Voluntary Commitments	5236
Coors Brewing Company		Waste Elim	PP	Other Solutions-Other Substitutes	3822
Coors Brewing Company		Waste Elim	PP	Procedures-Miscellaneous	3119
Coors Brewing Company		Industrial E	Cogeneration	Cogeneration-General	2341

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Coors Brewing Company		Waste Elim	PP	Waste Disposal	3613
Coors Brewing Company		Industrial E	Motor Systems and VFD	Air Compressors-Operations	2421
Coors Brewing Company		Other	Process Improvement		
Coors Brewing Company		Building an	HVAC	Space Conditioning-Operation	2722
Coors Brewing Company		Building an	Lighting	Hardware	2714
Cosmair, Inc. - Clark Facility		Building an	HVAC	Space Conditioning-Maintenance	2721
Cosmair, Inc. - Clark Facility		Building an	Lighting	Hardware	2714
Cosmair, Inc. - Clark Facility		Industrial E	Boiler	Blowdown	2124
Cosmair, Inc. - Clark Facility		Waste Elim	Water Use	General-Reduction	3412
Cosmair, Inc. - Clark Facility		Building an	Envelope	Building Envelope-Infiltration	2741
Cosmair, Inc. - Clark Facility		Industrial E	Motor Systems and VFD	Motors-Hardware	2412
Cosmair, Inc. - Clark Facility		Industrial E	Steam System	Maintenance	2215
Cosmair, Inc. - Clark Facility		Industrial E	Energy Management Operations	Demand Management-Miscellaneous	2312
Cosmair, Inc. - Clark Facility		Industrial E	Boiler	Maintenance	2123
Cosmair, Inc. - Clark Facility		Industrial E	Water Use	General-Painting Operations	3212
Cosmair, Inc. - Clark Facility		Corporate /	Energy Tracking/Reporting	Teams	5212
Cosmair, Inc. - Clark Facility		Corporate /	Community/Supplier Outreach/Education	Community Outreach	5221
Cosmair, Inc. - Clark Facility		Industrial E	Steam System	Steam- Traps	2211
Cosmair, Inc. - Clark Facility		Industrial E	Process Cooling	Cooling-Chillers and Refrigeration	2262
Cosmair, Inc. - Clark Facility		Building an	HVAC	Space Conditioning-Controls	2726
Cosmair, Inc. - Clark Facility		Corporate /	Energy Tracking/Reporting	Action Plan	5210
Cosmair, Inc. - Clark Facility		Industrial E	Boiler	Maintenance	2123
Cosmair, Inc. - Clark Facility		Industrial E	Energy Management Operations	Equipment Control-Equipment Automation	2623
Cosmair, Inc. - Clark Facility		Industrial E	Energy Management Operations	Administrative-Utility Costs	2811

AP Actions

Cosmair, Inc. - Clark Facility		Industrial E	Process Cooling	Cooling-Chillers and Refrigeration	2262
Cosmair, Inc. - Clark Facility		Industrial E	Energy Management Operations	Maintenance-General	2611
Cosmair, Inc. - Clark Facility		Waste Elim	Recycling	Other Materials-General	3531
Cosmair, Inc. - Clark Facility		Corporate .	Energy Audit	Audit	5231
Cosmair, Inc. - Clark Facility		Building an	HVAC	Space Conditioning-Controls	2726
Cosmair, Inc. - Clark Facility		Industrial E	Motor Systems and VFD	Air Compressors-Operations	2421
Cosmair, Inc. - Clark Facility		Industrial E	Energy Management Operations	Equipment Control-Equipment Use Reduction	2621
Cosmair, Inc. - Clark Facility		Waste Elim	Recycling	Other Materials-General	3531
Cosmair, Inc. - Clark Facility		Transporta	Transportation	General	5520
Cosmair, Inc. - Clark Facility		Industrial E	Process Heating	Furnaces, Ovens, and Directly Fired Operations-Hardware	2112
Cosmair, Inc. - Clark Facility		Building an	Lighting	Controls	2713
Cosmair, Inc. - Clark Facility		Building an	Envelope	Building Envelope-Infiltration	2741
Cosmair, Inc. - Clark Facility		Waste Elim	PP	Other- Leak Reduction	3731
Cosmair, Inc. - Clark Facility		Corporate .	Process Improvement	General	5234
Cosmair, Inc. - Somerset Facility	1		Boiler	Preheat Air	
Cosmair, Inc. - Somerset Facility	2		Steam System	Steam traps	
Cosmair, Inc. - Somerset Facility	3		Compressed Air	Upgrade	
Cosmair, Inc. - Somerset Facility	4		Compressed Air	Air leak repair	
Cosmair, Inc. - Somerset Facility	5		Compressed Air	Reduce air load	
Cosmair, Inc. - Somerset Facility	6		Process Improvement	Optimization	

AP Actions

Cosmair, Inc. - Somerset Facility	7		Process Improvement	Optimization	
Cosmair, Inc. - Somerset Facility	8		HVAC		
Cosmair, Inc. - Somerset Facility	9		Energy Audit		
Cosmair, Inc. - Somerset Facility	10		Transportation		
Cosmair, Inc. - Somerset Facility	11		Lighting		
Cosmair, Inc. - Somerset Facility	12		Recycling		
Cosmair, Inc. - Somerset Facility	13		Lighting		
Cosmair, Inc. - Somerset Facility	14		Energy Management Operations		
Cosmair, Inc. - Somerset Facility	15		HVAC		
Cosmair, Inc. - Somerset Facility	16		Motor Systems and VFD		
Cosmair, Inc. - Somerset Facility	17		HVAC		
Dade International, Inc.		Transporta	Transportation	Travel Reduction	5530
Dade International, Inc.		Building an	Lighting	Hardware	2714
Dade International, Inc.		Corporate .	Community/Supplier Outreach/Education	Community Outreach	5221
Dade International, Inc.		Waste Elin	PP	Procedures-Reduction/Elimi nation	3116
Dade International, Inc.		Waste Elin	Recycling	Other Materials-General	3531
Dade International, Inc.		Corporate .	Community/Supplier Outreach/Education	Employee Training	5233
Dade International, Inc.		Industrial E	Process Cooling	Cooling-Chillers and Refrigeration	2262
Dade International, Inc.		Other	PP	None	
Dade International, Inc.		Waste Elin	Recycling	Other Materials-General	3531

AP Actions

Dade International, Inc.		Waste Elir	PP	Waste Disposal	3613
Dade International, Inc.		Forestry	Forest Preservation/ Tree Planting	Tree Planting	5330
Dade International, Inc.		Corporate ,	Community/Supplier Outreach/Education	Employee Training	5233
Dade International, Inc.		Waste Elir	PP	Procedures-Product Specifications	3117
Dade International, Inc.		Waste Elir	PP	Procedures-Product Specifications	3117
Dade International, Inc.		Waste Elir	PP	Waste Stream Contamination-Miscellaneous	3123
Dave County Public Works	1		Fuel Switching		
Dave County Public Works	2		Process Improvement	Optimization	
De Bourgh Manufacturing Company		Industrial E	Process Improvement	General-Painting Operations	3212
De Bourgh Manufacturing Company		Industrial E	Process Heating	Furnaces, Ovens, and Directly Fired Operations-Hardware	2112
De Bourgh Manufacturing Company		Industrial E	Motor Systems and VFD	Air Compressors-Operations	2421
De Bourgh Manufacturing Company		Industrial E	Motor Systems and VFD	Air Compressors-Operations	2421
De Bourgh Manufacturing Company		Building an	HVAC	Space Conditioning-Hardware- Air Circulation	2724
De Bourgh Manufacturing Company		Building an	HVAC	Space Conditioning-Controls	2726
De Bourgh Mfg. Co.			Office		
De Bourgh Mfg. Co.			Lighting		
De Bourgh Mfg. Co.			Process Heating		
Delaware Solid Waste Athority	1		PP		
Delaware Solid Waste Athority	2		PP		

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Delaware Solid Waste Athority	3		PP		
Delaware Solid Waste Athority	4		Fuel Switching		
Dell Computer Corporation			Process Cooling		
Dell Computer Corporation			Energy Management Operations		
Dell Computer Corporation			HVAC		
Dell Computer Corporation			Compressed Air		
Dell Computer Corporation			Recycling		
Dell Computer Corporation			PP		
Dell Computer Corporation			Process Heating	Instalation	
Dell Computer Corporation			Recycling		
Dell Computer Corporation			Envelope		
Dell Computer Corporation			Recycling		
Dell Computer Corporation			Motor Systems and VFD		
Dell Computer Corporation			Envelope		
Dell Computer Corporation			Process Improvement		
Dell Computer Corporation			Process Improvement		
Dell Computer Corporation			PP		
Dell Computer Corporation					
Dell Computer Corporation			Energy Audit		
Dell Computer Corporation			Office		
Dell Computer Corporation			Envelope		
Dell Computer Corporation			Water Use		
Dell Computer Corporation			Transportation		

AP Actions

Dell Computer Corporation			Process Improvement		
Dell Computer Corporation			Transportation		
Dell Computer Corporation			Office		
Dell Computer Corporation			Process Improvement		
Dell Computer Corporation			Community/Supplier Outreach/Education		
Dell Computer Corporation			Lighting		
Dell Computer Corporation			Lighting		
Dell Computer Corporation					
Dell Computer Corporation			Lighting		
Dell Computer Corporation			Lighting		
Dell Computer Corporation					
Dell Computer Corporation			Process Improvement		
Dell Computer Corporation			Envelope		
Dell Computer Corporation			PP		
Dell Computer Corporation					
Design Plastics Inc	1		Process Cooling	Upgrade	
Design Plastics Inc	2		Motor Systems and VFD		
Design Plastics Inc	3		Motor Systems and VFD		
Design Plastics Inc	4		Compressed Air	Optimizing	
Design Plastics Inc	5		Compressed Air	Air leak	
Design Plastics Inc	6		Energy Audit		
Design Plastics Inc	7		Process Improvement	Optimzation	
Design Plastics Inc	8		Energy Management Operations		
Design Plastics Inc	9		Lighting		

AP Actions

Design Plastics Inc	10		Office		
Design Plastics Inc	11		HVAC		
Design Plastics Inc	12		HVAC		
Design Plastics Inc	13		Recycling		
Design Plastics Inc	14		PP		
Design Plastics Inc	15		Insulation		
Design Plastics Inc	16		Recycling		
Design Plastics Inc	17		Lighting		
Design Plastics Inc	18		Recycling		
Doug Scales Body Shop Inc.	1		Lighting		
Doug Scales Body Shop Inc.	2		Transportation		
Doug Scales Body Shop Inc.	3		Recycling		
Doug Scales Body Shop Inc.	4		Recycling		
Doug Scales Body Shop Inc.	5		HVAC		
Doug Scales Body Shop Inc.	6		Envelope		
Doug Scales Body Shop Inc.	7		HVAC		
Doug Scales Body Shop Inc.	8		Process Improvement	Upgrade	
Doug Scales Body Shop, Inc.		Waste Elim	Recycling	Other Materials-General	3531
Doug Scales Body Shop, Inc.		Waste Elim	Recycling	Solvents-Solvent Recovery	3814
Doug Scales Body Shop, Inc.		Waste Elim	Recycling	Other Materials-General	3531
Doug Scales Body Shop, Inc.		Building an	Lighting	Hardware	2714
Doug Scales Body Shop, Inc.		Transporta	Energy Management Operations	Shipping, Distribution, and Transportation-Shipping	2822
Doug Scales Body Shop, Inc.		Waste Elim	Process Improvement	General-Painting Operations	3212
Doug Scales Body Shop, Inc.		Waste Elim	PP	General-Automation	3215
Doug Scales Body Shop, Inc.		Waste Elim	PP	CFC	5610
Doug Scales Body Shop, Inc.		Building an	HVAC	Space Conditioning-Hardware-Heating/Cooling	2723
Doug Scales Body Shop, Inc.		Waste Elim	PP	General-Process Specific Upgrades	3213

AP Actions

Doug Scales Body Shop, Inc.		Waste Elir	PP	CFC	5610
Doug Scales Body Shop, Inc.		Waste Elir	Recycling	Solid Waste-Metals	3523
Doug Scales Body Shop, Inc.		Building an	Envelope	Building Envelope-Infiltration	2741
DOW Chemical Company		Corporate .	Energy Management Operations	Tracking Activities	5242
DOW Chemical Company		Corporate .	Energy Management Operations	Tracking Activities	5242
DOW Chemical Company		Industrial E	Boiler	Boilers-Hardware	2122
DOW Chemical Company		Corporate .	Energy Management Operations	Reporting	5241
DOW Chemical Company		Waste Elir	PP	CFC	5610
DOW Chemical Company		Corporate .	Energy Management Operations	Reporting	5241
DOW Chemical Company		Waste Elir	PP	Solvents-Material Replacement	3813
DOW Chemical Company		Green Proc	PP	CFC	5410
DOW Chemical Company		Waste Elir	PP	Solids- General	3831
DOW Chemical Company		Industrial E	Motor Systems and VFD	Motors-Hardware	2412
DOW Chemical Company		Green Proc	Insulation	General	5420
DOW Chemical Company		Corporate .	Energy Management Operations	Management Structure	5235
DOW Chemical Company		Industrial E	Cogeneration	Cogeneration-General	2341
DOW Chemical Company		Industrial E	Cogeneration	Cogeneration-General	2341
DOW Chemical Company		Corporate .	Energy Tracking/Reporting	Action Plan	5211

DuPont		Waste Elim	PP	CFC	5610
DuPont		Corporate /	Energy Management Operations	Tracking Activities	5242
		Climate Wise Company Actions			
DuPont		Corporate /	Energy Management Operations	Performance Targets	5237
DuPont		Waste Elim	PP	CFC	5610
DuPont		Waste Elim	PP	Procedures-Miscellaneous	3119
DuPont		Waste Elim	PP	CFC	5610
DuPont		Corporate /	Energy Management Operations	Reporting	5241
DuPont		Corporate /	Energy Management Operations	Management Structure	5235
EcoTours of Oregon		Building an	Lighting	Hardware	2714
EcoTours of Oregon		Waste Elim	Recycling	Paper	3117
EcoTours of Oregon		Building an	Envelope	Building Envelope-Infiltration	2741
Engelhard/ICC		Corporate /	Community/Supplier Outreach/Education	Employee Training	5233
Engelhard/ICC		Forestry	Forest Preservation/ Tree Planting	Tree Planting	5330
Engelhard/ICC		Building an	HVAC	Space Conditioning-Controls	2726
Engelhard/ICC		Transporta	Transportation	General	5520
Engelhard/ICC		Waste Elim	Process Improvement	Procedures-Product Specifications	3117
Engelhard/ICC		Waste Elim	Recycling	Other Materials-General	3531
Environmental Technologies International		Waste Elim	Recycling	Procedures-Product Specifications	3117
Environmental Technologies International		Green Proc	Transportation	Product Improvement	5420
Environmental Technologies International		Transporta	Transportation	Travel Reduction	5530

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Environmental Technologies International		Corporate .	Community/Supplier Outreach/Education	Employee Training	5233
Environmental Technologies International		Transporta	Transportation	Travel Reduction	5530
Environmental Technologies International		Waste Elin	Recycling	Other Materials-General	3531
Essorc Cement Corp - San Juan	1		Motor Systems and VFD	VFD	
Essorc Cement Corp - San Juan	2		Motor Systems and VFD	VFD	
Essorc Cement Corp - San Juan	3		Process Improvement		
Essorc Cement Corp - San Juan	4		Process Improvement		
Essorc Cement Corp - San Juan	5		Process Improvement		
Essorc Cement Corp - San Juan	6		Process Improvement		
Essorc Cement Corp - San Juan	7		Process Improvement		
Essorc Cement Corp - San Juan	8		Process Improvement		
Essroc Cement Corp. - Bessemer	1		Motor Systems and VFD	VFD	
Essroc Cement Corp. - Bessemer	2		Process Improvement		
Essroc Cement Corp. - Bessemer	3		Heat Exchanger/ Recovery		
Essroc Cement Corp. - Bessemer	4		Process Heating		
Essroc Cement Corp. - Bessemer	5		Energy Management Operations		
Essroc Cement Corp. - Bessemer	6		Process Improvement		
Essroc Cement Corp. - Bessemer	7		Process Improvement		
Essroc Cement Corp. - Bessemer	8		Process Improvement		
Essroc Cement Corp. - Logansport	1		Motor Systems and VFD	VFD	
Essroc Cement Corp. - Logansport	2		Motor Systems and VFD	VFD	
Essroc Cement Corp. - Logansport	3		Motor Systems and VFD	VFD	
Essroc Cement Corp. - Speed	1		Process Heating		
Essroc Cement Corp. - Speed	2		Process Improvement		
Essroc Cement Corp. - Speed	3		Energy Management Operations		

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Essroc Cement Corp. - Speed	4		Process Heating		
Essroc Cement Corp. - Speed	5		Process Heating		
Essroc Cement Corp. - Speed	6		Process Improvement		
Essroc Cement Corp. - Speed	7		Heat Exchanger/ Recovery		
Essroc Cement Corp. - Speed	8		Process Cooling		
Essroc Cement Corp. - Speed	9		Fuel Switching		
Essroc Cement Corp. - Speed	10		Process Improvement		
ETTA Industries, Inc.		Building an	Lighting	Hardware	2714
ETTA Industries, Inc.		Corporate .	Process Improvement	General	5234
ETTA Industries, Inc.		Building an	Lighting	Hardware	2714
Fetzer Vineyards		Waste Elin	PP	Other Solutions-Other Substitutes	3822
Fetzer Vineyards		Waste Elin	Recycling	Other Materials-General	3531
Fetzer Vineyards		Waste Elin	PP	Solids- General	3831
Fetzer Vineyards		Waste Elin	PP	Procedures-Reduction/Elimi nation	3116
Fetzer Vineyards		Transporta	Transportation	Alternative Fuel Vehicles	5510
Fetzer Vineyards		Industrial E	Alternative Energy	General- Solar	2911
Fetzer Vineyards		Building an	HVAC	Space Conditioning-Hardware-Heating/Cooling	2723
Fetzer Vineyards		Corporate .	Process Improvement	General	5234
Fetzer Vineyards		Waste Elin	PP	Procedures-Product Specifications	3117
Ford Microelectronics			PP		

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Ford Microelectronics			Recycling		
Ford Microelectronics			Recycling		
Ford Microelectronics			Lighting		
Ford Microelectronics			Motor Systems and VFD		
Ford Microelectronics			Lighting		
General Motors Corporation		Corporate .	Energy Audit	Audit	5231
General Motors Corporation		Building an	Lighting	Hardware	2714
General Motors Corporation		Corporate .	Energy Tracking/Reporting	Action Plan	5211
General Motors Corporation		Industrial E	Boiler	Boilers-Hardware	2122
General Motors Corporation		Industrial E	Cogeneration	Cogeneration-General	2341
General Motors Corporation		Transporta	Transportation	Travel Reduction	5530
General Motors Corporation		Green Proc	Process Improvement	Product Improvement	5420
General Motors Corporation		Corporate .	Community/Supplier Outreach/Education	Employee Competitions	5232
General Motors Corporation		Corporate .	Community/Supplier Outreach/Education	Supplier Outreach	5222

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General Motors Corporation		Forestry	Forest Preservation/ Tree Planting	General	5310
General Motors Corporation		Corporate .	PP	Other Voluntary Commitments	5236
General Motors Corporation		Corporate .	Community/Supplier Outreach/Education	Other Voluntary Commitments	5236
General Motors Corporation		Corporate Activities		Management Structure	5235
General Motors Corporation		Industrial E	Motor Systems and VFD	Motors-Hardware	2412
General Motors Corporation		Corporate .	PP	Other Voluntary Commitments	5236
General Motors Corporation		Waste Elin	PP	CFC	5610
General Motors Corporation		Corporate .	Process Improvement	Other Voluntary Commitments	5236
General Motors Corporation		Corporate .	Transportation	Other Voluntary Commitments	5236
General Motors Corporation		Corporate .	Energy Audit	Audit	5231
General Motors Corporation		Corporate .	Community/Supplier Outreach/Education	Employee Training	5233
General Motors Corporation		Waste Elin	PP	Solvents-Material Replacement	3813
General Motors Corporation		Waste Elin	PP	Procedures-Reduction/Elimination	3116
General Motors Corporation		Waste Elin	Recycling	Other Materials-General	3531
General Motors Corporation		Corporate .	Energy Management Operations	Reporting	5241
Georgia-Pacific Corporation		Corporate .	Energy Management Operations	General	5234

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Georgia-Pacific Corporation		Corporate	Community/Supplier Outreach/Education	Employee Training	5233
Georgia-Pacific Corporation		Industrial E	Boiler	Boilers-Hardware	2122
Georgia-Pacific Corporation		Corporate	Community/Supplier Outreach/Education	Employee Training	5233
Georgia-Pacific Corporation		Industrial E	Energy Management Operations	Administrative-Fiscal	2812
Georgia-Pacific Corporation		Building an	Lighting	Hardware	2714
Georgia-Pacific Corporation		Waste Elim	Recycling	Other Materials-General	3531
Georgia-Pacific Corporation		Transporta	Energy Management Operations	Shipping, Distribution, and Transportation-Shipping	2822
Georgia-Pacific Corporation		Corporate	Energy Management Operations	Reporting	5241
Georgia-Pacific Corporation		Corporate	Energy Management Operations	Reporting	5241
Globla Solar Energy	1		Lighting		
Globla Solar Energy	2		HVAC		
Globla Solar Energy	3		Envelope		
Globla Solar Energy	4		HVAC		
Globla Solar Energy	5		Water Use		
Globla Solar Energy	6		Alternative Energy		
Hallmark Cards, Inc.		Waste Elim	PP	Solvents-Emission Reduction	3812
Hallmark Cards, Inc.		Corporate Activities		Performance Targets	5237
Hallmark Cards, Inc.		Waste Elim	PP	Procedures-Miscellaneous	3119
Hallmark Cards, Inc.		Waste Elim	PP	Procedures-Miscellaneous	3119
Hass-Cal Industries, Inc.			Process Improvement		
Hass-Cal Industries, Inc.			Process Improvement		
Henningsen Foods		Industrial E	Heat Exchanger/ Recovery	Heat Recovery-Heat Recovery from Specific Equipment	2243
Henningsen Foods		Industrial E	Insulation	Heat Containment-Insulation	2251
Henningsen Foods		Industrial E	Insulation	Heat Containment-Insulation	2251

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Henningsen Foods		Building an	Lighting	Hardware	2714
Henningsen Foods		Industrial E	Steam System	Steam- Leaks and Insulation	2213
Henningsen Foods		Waste Elir	Recycling	Other Materials- General	3531
Henningsen Foods		Industrial E	Motor Systems and VFD	Motors- Hardware	2412
Henningsen Foods		Industrial E	Boiler	Boilers- Maintenance	2123
Henningsen Foods		Industrial E	Heat Exchanger/ Recovery	Heat Recovery- Heat Recovery from Specific Equipment	2243
Henningsen Foods		Waste Elir	Recycling	Solid Waste- General	3521
Henningsen Foods		Waste Elir	Water Use	General- Close Cycle Water Use	3411
Henningsen Foods			Water Use		
Henningsen Foods		Industrial E	Motor Systems and VFD	Motors- Hardware	2412
Henningsen Foods		Building an	Lighting	Hardware	2714
Henningsen Foods		Industrial E	Steam System	Steam- Condensate	2212
Henningsen Foods		Industrial E	Motor Systems and VFD	Air Compressors- Operations	2421
Hewlett-Packard - Vancouver Site		Waste Elir	Recycling	Other Materials- General	3531
Hewlett-Packard - Vancouver Site		Industrial E	Motor Systems and VFD	Motors- Hardware	2412
Hewlett-Packard - Vancouver Site		Industrial E	Process Cooling	Cooling- Chillers and Refrigeration	2262

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Hewlett-Packard - Vancouver Site		Industrial E	Process Cooling	Cooling-Chillers and Refrigeration	2262
Hewlett-Packard - Vancouver Site		Industrial E	Process Cooling	Cooling-Chillers and Refrigeration	2262
Hewlett-Packard - Vancouver Site		Industrial E	Motor Systems and VFD	Motors-Hardware	2412
Hewlett-Packard - Vancouver Site		Industrial E	Motor Systems and VFD	Motors-Hardware	2412
Hewlett-Packard - Vancouver Site		Building an	Lighting	Hardware	2714
Hewlett-Packard - Vancouver Site		Building an	Lighting	Hardware	2714
Hewlett-Packard - Vancouver Site		Building an	Lighting	Operation	2712
Hewlett-Packard - Vancouver Site			PP		
Hewlett-Packard - Vancouver Site		Transporta	Transportation	Travel Reduction	5530
Hewlett-Packard - Vancouver Site		Waste Elin	Water Use	General-Reduction	3412
Hewlett-Packard - Vancouver Site		Building an	Lighting	Operation	2712
Homasote Company		Building an	Lighting	Hardware	2714
Homasote Company		Industrial E	Process Heating	Systems-Thermal	2511
Homasote Company			Recycling		
IBM Corporation			Energy Management Operations		
IBM Corporation					
IBM Corporation			Community/Supplier Outreach/Education	Education	
IBM Corporation			Lighting		
IBM Corporation			Lighting		
IBM Corporation			PP		
IBM Corporation			Process Improvement		
IBM Corporation			HVAC		

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IBM Corporation			Recycling		
IBM Corporation			Energy Tracking/Reporting		
IBM Corporation			Process Improvement		
IBM Corporation			PP		
IBM Corporation			HVAC		
Industrial Equipment & Supplies	1		PP		
Industrial Equipment & Supplies	2		PP		
Industrial Equipment & Supplies	3		PP		
Industrial Equipment & Supplies	4		Recycling		
Industrial Equipment & Supplies	5		Recycling		
Industrial Equipment & Supplies	6		Recycling		
Industrial Equipment & Supplies	7		Lighting		
Johnson & Johnson		Building an	Lighting	Hardware	2714
Johnson & Johnson		Waste Elin	Office	Procedures-Miscellaneous	3119
Johnson & Johnson		Waste Elin	Recycling	Other Materials-General	3531
Johnson & Johnson		Industrial E	Motor Systems and VFD	Motors-Hardware	2412
Johnson & Johnson		Waste Elin	PP	Procedures-Miscellaneous	3119
Johnson & Johnson		Corporate	Community/Supplier Outreach/Education	Employee Training	5233
Johnson & Johnson		Corporate	Community/Supplier Outreach/Education	Community Outreach	5221
Johnson & Johnson		Green Proc	PP	CFC	5410
Johnson & Johnson		Waste Elin	PP	CFC	5610
Lafarge Corporation - Fredonia	1		Compressed Air		
Lafarge Corporation - Fredonia	2		Process Heating		
Lafarge Corporation - Paulding	1		Process Heating		
Lafarge Corporation - Paulding	2		Process Heating		

Lafarge Corporation - Paulding	3		Process Cooling		
Lafarge Corporation - Sugar Creek	1		Process Improvement		
Lafarge Corporation - Sugar Creek	2		Process Improvement		
Lafarge Corporation - Whitehall	1		Motor Systems and VFD	VFD	
Lafarge Corporation - Whitehall	2		Process Improvement		
Lafarge Corporation - Whitehall	3		Process Improvement		
Lafarge Corporation - Whitehall	4		Process Heating		
Lafarge Corporation - Whitehall	5		Process Improvement		
Lafarge Corporation - Whitehall	6		Process Improvement		
Lafarge Corporation - Whitehall	7		Process Improvement		
Lafarge Corporation - Whitehall	8		Process Improvement	VFD	
Lehigh	1		Process Improvement		
Lehigh	2		Fuel Switching		
Lehigh	3		Fuel Switching		
Lehigh	4		Process Heating		
Lehigh	5		Lighting		
Lehigh	6		Motor Systems and VFD		
Liquid Sugars, Inc.		Waste Elim	PP	Post Generation Treatment/ MinimizationRemoval of Contaminants	3312
Liquid Sugars, Inc.		Industrial E	Process Improvement	Systems-Miscellaneous	2513
Liquid Sugars, Inc.		Waste Elim	Recycling	Solid Waste-General	3521
Liquid Sugars, Inc.		Waste Elim	Recycling	Liquid Waste-Oil	3511
Liquid Sugars, Inc.		Waste Elim	PP	Other Solutions-Other Substitutes	3822

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Lockheed Martin		Corporate /	Energy Tracking/Reporting	Teams	5212
Lockheed Martin		Corporate /	Community/Supplier Outreach/Education	Employee Training	5233
Lockheed Martin		Corporate /	Energy Audit	Audit	5231
Lockheed Martin		Corporate /	Energy Audit	Audit	5231
Lockheed Martin		Corporate /	Energy Tracking/Reporting	Action Plan	5211
Lockheed Martin		Corporate /	Energy Management Operations	Tracking Activities	5242
Lockheed Martin		Corporate /	Energy Tracking/Reporting	Action Plan	5211
Majestic Metals		Building an	HVAC	Space Conditioning-Controls	2726
Majestic Metals		Building an	Office	Energy Efficient Equipment	5110
Majestic Metals		Building an	HVAC	Space Conditioning-Miscellaneous	2728
Majestic Metals		Waste Elim	PP	Cleaning/Degreasing- Rag Use	3713
Majestic Metals		Industrial E	Process Improvement	General-Painting Operations	3212
Majestic Metals		Waste Elim	Recycling	Solvents-Solvent Recovery	3814
Majestic Metals		Green Proc	PP	CFC	5410
Majestic Metals		Waste Elim	PP	CFC	5610
Majestic Metals		Building an	Lighting	Hardware	2714
Majestic Metals		Building an	Lighting	Hardware	2714

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Majestic Metals		Waste Elin	PP	Solvents-Material Replacement	3813
Majestic Metals		Waste Elin	Recycling	Procedures-Product Specifications	3117
Majestic Metals		Waste Elin	Recycling	Other Materials-General	3531
Majestic Metals		Waste Elin	PP	Waste Stream Contamination-Rinsing Strategies	3122
Majestic Metals		Waste Elin	PP	Other Solutions-Other Substitutes	3822
Majestic Metals		Building an	HVAC	Space Conditioning-Controls	2726
Majestic Metals		Industrial E	Insulation	Heat Containment-Insulation	2251
Majestic Metals		Waste Elin	Recycling	Procedures-Product Specifications	3117
Majestic Metals		Industrial E	Motor Systems and VFD	Air Compressors-Hardware	2422
Majestic Metals		Building an	Envelope	Building Envelope-Infiltration	2741
Majestic Metals		Industrial E	Process Heating	Furnaces, Ovens, and Directly Fired Operations-Hardware	2112
Majestic Metals		Building an	HVAC	Space Conditioning-Controls	2726
Majestic Metals		Building an	HVAC	Space Conditioning-Hardware-Heating/Cooling	2723
Majestic Metals		Waste Elin	Recycling	Solid Waste-Metals	3523

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Maui Pineapple Company, Ltd.		Waste Elin	Recycling	Other Materials-General	3531
Maui Pineapple Company, Ltd.		Waste Elin	PP	General-Material Concentration	3313
Merix Corporation		Corporate .	Energy Management Operations	General	5234
Merix Corporation		Other	PP	None	
Merix Corporation		Transporta	Transportation	General	5520
Merix Corporation		Industrial E	Energy Management Operations	Administrative-Utility Costs	2811
Merix Corporation		Corporate .	Energy Management Operations	Tracking Activities	5242
Midwest Research Institute		Waste Elin	Recycling	Other Materials-General	3531
Midwest Research Institute		Industrial E	Process Cooling	Cooling-Miscellaneous	2263
Midwest Research Institute		Building an	Lighting	Hardware	2714
Midwest Research Institute		Industrial E	Process Cooling	Cooling-Chillers and Refrigeration	2262
Midwest Research Institute		Building an	HVAC	Space Conditioning-Maintenance	2721
Midwest Research Institute		Building an	HVAC	Space Conditioning-Evaporation	2725
Midwest Research Institute		Waste Elin	Recycling	Other Materials-General	3531
Midwest Research Institute		Industrial E	Boiler	Boilers-Maintenance	2123
Midwest Research Institute		Building an	Envelope	Building Envelope-Infiltration	2741
Midwest Research Institute		Building an	Lighting	Hardware	2714
Midwest Research Institute		Waste Elin	Recycling	Procedures-Product Specifications	3117

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Midwest Research Institute		Waste Elin	Process Improvement	Procedures-Miscellaneous	3119
Mobile Tool International, Inc.			Recycling		
Mobile Tool International, Inc.			Process Improvement		
Mobile Tool International, Inc.			Insulation		
Mobile Tool International, Inc.			Motor Systems and VFD		
Mobile Tool International, Inc.			Recycling		
Mobile Tool International, Inc.			Water Use		
Mobile Tool International, Inc.			Process Improvement		
Mobile Tool International, Inc.			Lighting		
Mobile Tool International, Inc.			Recycling		
Mobile Tool International, Inc.			Recycling		
Mobile Tool International, Inc.			Water Use		
Mobile Tool International, Inc.			Recycling		
Mobile Tool International, Inc.			PP		
Mobile Tool International, Inc.			Compressed Air	Outside air intake	
Mobile Tool International, Inc.			PP		
Motorola Austin			HVAC		
Motorola Austin			Recycling		
Motorola Austin			Motor Systems and VFD		

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Motorola Austin			Steam System	Optimizing	
Motorola Austin			HVAC		
Motorola Austin			Process Improvement		
Motorola Austin			Lighting		
Motorola Austin			Boiler	Optimization	
Motorola Austin					
National Cement Co.	1		Process Improvement		
National Cement Co.	2		Process Heating		
Nexstar Pharmaceuticals, Inc.		Waste Elir	Recycling	Solid Waste-Metals	3523
Nexstar Pharmaceuticals, Inc.		Building an	Lighting	Controls	2713
Nexstar Pharmaceuticals, Inc.		Waste Elir	Recycling	Solid Waste-Metals	3523
Nexstar Pharmaceuticals, Inc.		Waste Elir	PP	Waste Disposal	3613
Nexstar Pharmaceuticals, Inc.		Waste Elir	Recycling	Other Materials-General	3531
Nexstar Pharmaceuticals, Inc.		Waste Elir	PP	Other Solutions-Other Substitutes	3822
Nexstar Pharmaceuticals, Inc.		Waste Elir	PP	Other Solutions-Other Substitutes	3822
Nexstar Pharmaceuticals, Inc.		Waste Elir	Recycling	Other Materials-General	3531
Nexstar Pharmaceuticals, Inc.		Waste Elir	PP	Procedures-Miscellaneous	3119
Nexstar Pharmaceuticals, Inc.		Building an	Lighting	Hardware	2714

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Nexstar Pharmaceuticals, Inc.		Building an	Lighting	Hardware	2714
Nexstar Pharmaceuticals, Inc.		Waste Elin	Recycling	Other Materials-General	3531
Nexstar Pharmaceuticals, Inc.		Waste Elin	Recycling	Other Materials-General	3531
Nexstar Pharmaceuticals, Inc.		Waste Elin	PP	Other Solutions-Other Substitutes	3822
Nuffer, Smith, Tucker, Inc.		Waste Elin	Recycling	Other Materials-General	3531
Nuffer, Smith, Tucker, Inc.		Waste Elin	Recycling	Other Materials-General	3531
Nuffer, Smith, Tucker, Inc.		Waste Elin	Recycling	Other Materials-General	3531
Pacific Coast Producers		Industrial E	Boiler	Boilers-Hardware	2122
Pacific Coast Producers		Other	Process Improvement	None	
Pacific Coast Producers		Waste Elin	PP	Solvents-Emission Reduction	3812
Pacific Coast Producers		Industrial E	Boiler	Boilers-Hardware	2122
Pacific Energy Systems, Inc.		Other	PP	Paper	
Pacific Energy Systems, Inc.		Other	Recycling	Paper	
Pacific Energy Systems, Inc.		Corporate /	Energy Tracking/Reporting	Action Plan	5211
Pacific Energy Systems, Inc.		Transporta	Transportation	Travel Reduction	5530
Pacific Energy Systems, Inc.		Other	Recycling	Paper	
Pacific Energy Systems, Inc.		Corporate /	Community/Supplier Outreach/Education	Supplier Outreach	5222

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Pacific Energy Systems, Inc.	Waste Elir	Recycling	Other Materials-General	3531
Pacific Energy Systems, Inc.	Corporate .	PP	Other Voluntary Commitments	5236
Pacific Gas Transmission Company	Transporta	Transportation	Travel Reduction	5530
Pacific Gas Transmission Company	Building an	Lighting	Operation	2712
Pacific Gas Transmission Company	Transporta	Transportation	Travel Reduction	5530
Pacific Gas Transmission Company	Waste Elir	Recycling	Other Materials-General	3531
Pacific Gas Transmission Company	Waste Elir	Recycling	Procedures-Product Specifications	3117
Pacific Gas Transmission Company	Corporate .	Energy Management Operations	Tracking Activities	5242
Pacific Gas Transmission Company	Corporate .	Energy Management Operations	Tracking Activities	5242
Pacific Northwest National Laboratory	Building an	Lighting	Hardware	2714
Pacific Northwest National Laboratory	Transporta	Transportation	General	5520
Pacific Northwest National Laboratory	Industrial E	Energy Management Operations	Administrative-Fiscal	2812
Pacific Northwest National Laboratory	Waste Elir	Recycling	Liquid Waste-Oil	3511
Pacific Northwest National Laboratory	Industrial E	Heat Exchanger/ Recovery	Heat Recovery-Other Process Waste Heat	2244
Pacific Northwest National Laboratory	Waste Elir	Energy Management Operations	Procedures-Reduction/Elimi nation	3116
Pacific Northwest National Laboratory	Waste Elir	Recycling	Other Materials-General	3531
Pacific Northwest National Laboratory	Corporate .	PP	Other Voluntary Commitments	5236

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Pacific Northwest National Laboratory		Waste Elin	Water Use	General-Removal of Contaminants	3312
Pacific Northwest National Laboratory		Waste Elin	Recycling	Other Materials-General	3531
Pacific Northwest National Laboratory		Waste Elin	Recycling	Other Materials-General	3531
Pacific Northwest National Laboratory		Waste Elin	Recycling	Other Materials-General	3531
Pacific Northwest National Laboratory		Waste Elin	Recycling	Other Materials-General	3531
Pacific Northwest National Laboratory		Waste Elin	Recycling	Solvents-Solvent Recovery	3814
Pacific Northwest National Laboratory		Building an	Lighting	Operation	2712
Pacific Northwest National Laboratory		Industrial E	Heat Exchanger/ Recovery	Heat Recovery-Other Process Waste Heat	2244
Pacific Northwest National Laboratory		Waste Elin	Recycling	Liquid Waste-Miscellaneous	3514
Pak-Lite, Inc.		Industrial E	Steam System	Steam-Condensate	2212
Pak-Lite, Inc.		Industrial E	Process Improvement	Systems-Miscellaneous	2513
Pan American Hospital		Other	Energy Management Operations	None	
Parker Pen USA Ltd.		Corporate	Energy Tracking/Reporting	Teams	5212
Parker Pen USA Ltd.		Industrial E	Boiler	Hardware	2122
Parker Pen USA Ltd.		Industrial E	Energy Management Operations	Administrative-Utility Costs	2811
Parker Pen USA Ltd.		Corporate	Community/Supplier Outreach/Education	Employee Training	5233
Parker Pen USA Ltd.		Building an	Lighting	Hardware	2714
Parker Pen USA Ltd.		Other	Process Improvement		
Parker Pen USA Ltd.		Building an	Lighting	Hardware	2714
Parker Pen USA Ltd.		Industrial E	Motor Systems and VFD	Air Compressors-Operations	2421

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Parker Pen USA Ltd.		Building an	HVAC	Space Conditioning-Hardware-Heating/Cooling	2723
Parker Pen USA Ltd.		Industrial E	Motor Systems and VFD	Air Compressors-Hardware	2422
Parker Pen USA Ltd.		Industrial E	Fuel Switching	Fuel Switching-Alternate Fossil Fuel	2133
Parker Pen USA Ltd.		Other	Process Improvement	None	
Parker Pen USA Ltd.		Industrial E	Process Cooling	Cooling-Miscellaneous	2263
Peacetree Environmentally Sound Paper & Printing		Corporate ,	Community/Supplier Outreach/Education	Supplier Outreach	5222
Peacetree Environmentally Sound Paper & Printing		Other	PP	Paper	
Peacetree Environmentally Sound Paper & Printing		Other	PP	Paper	
Peacetree Environmentally Sound Paper & Printing		Other	PP	Paper	
Perko, Inc.		Waste Elir	Recycling	Solvents-Solvent Recovery	3814
Perko, Inc.		Waste Elir	Recycling	Other Materials-General	3531
Perko, Inc.		Waste Elir	Recycling	Liquid Waste-Oil	3511
Perko, Inc.		Waste Elir	Recycling	Other Materials-General	3531
Perko, Inc.		Waste Elir	Recycling	Solid Waste-Metals	3523
Perko, Inc.		Other	PP	None	
Perko, Inc.		Waste Elir	Recycling	Solid Waste-Sand	3522
Perko, Inc.		Waste Elir	Recycling	Other Materials-General	3531

AP Actions

Planar America		Waste Elin	PP	Solvents- Use Reduction	3811
Planar America		Waste Elin	PP	Solvents- Material Replacement	3813
Planar America		Waste Elin	PP	Solvents- Use Reduction	3811
Planar America		Building an	HVAC	Space Conditioning- Controls	2726
Planar America		Waste Elin	Water Use	General- Close Cycle Water Use	3411
Polaroid Corporation			Energy Management Operations		
Polaroid Corporation			Community/Supplier Outreach/Education	Education	
Polaroid Corporation			PP		
Polaroid Corporation			Cogeneration		
Polaroid Corporation			HVAC		
Polaroid Corporation			Lighting		
Polaroid Corporation			Energy Management Operations		
Polaroid Corporation			Energy Audit		
Polaroid Corporation			Boiler	Optimzation	

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Polaroid Corporation			Energy Management Operations		
Polaroid Corporation			Envelope		
Promega Co	1		Motor Systems and VFD		
Promega Co	2		Lighting		
Promega Co	3		Lighting		
Promega Co	4		Lighting		
Promega Co	5		PP		
Promega Co	6		Recycling		
Promega Co	7		Envelope		
Promega Co	8		HVAC		
Promega Co	9		Lighting		
Promega Co	10		Lighting		
Promega Co	11		HVAC		
Promega Co	12		Energy Management Operations		
Promega Co	13		Boiler	Load Managment	
Promega Co	14		Recycling		
Promega Co	15		Boiler	Upgrade	
Promega Co	16		Lighting		
Promega Co	17		Transportation		
Promega Co	18		Energy Audit		
Promega Co	19		Lighting		
Puerto Rico Ports Authority		Corporate .	Lighting	Other Voluntary Commitments	5236
Puerto Rico Ports Authority		Waste Elir	Recycling	Other Materials-General	3531
Puerto Rico Ports Authority		Corporate .	Energy Management Operations	Tracking Activities	5242
Puerto Rico Ports Authority		Corporate .	Energy Audit	Audit	5231
Puerto Rico Ports Authority		Building an	Lighting	Hardware	2714
Quad/Graphics, Inc.		Corporate .	Envelope	General	5234
Quad/Graphics, Inc.		Industrial E	Heat Exchanger/ Recovery	Heat Recovery-Other Process Waste Heat	2244
Quad/Graphics, Inc.		Transporta	Transportation	Alternative Fuel Vehicles	5510

AP Actions

Quad/Graphics, Inc.		Waste Elin	PP	Solvents- Solvent Recovery	3814
Quad/Graphics, Inc.		Waste Elin	PP	Solids- General	3831
Quad/Graphics, Inc.		Waste Elin	PP	Procedures- Reduction/Elimi nation	3116
Quad/Graphics, Inc.		Forestry	Forest Preservation/ Tree Planting	Tree Planting	5330
Quad/Graphics, Inc.		Building an	Lighting	Hardware	2714
Quad/Graphics, Inc.		Industrial E	Energy Management Operations	Administrative- Fiscal	2812
Quad/Graphics, Inc.		Transporta	Transportation	General	5520
Quad/Graphics, Inc.		Waste Elin	Recycling	Other Materials- General	3531
Quad/Graphics, Inc.		Industrial E	Process Heating	Furnaces, Ovens, and Directly Fired Operations- Operations	2111
Quad/Graphics, Inc.		Building an	Office	Energy Efficient Equipment	5110
Quad/Graphics, Inc.		Corporate	Community/Supplier Outreach/Education	Employee Training	5233
Quad/Graphics, Inc.		Corporate	Process Improvement	General	5234
Regis University	1		Lighting		
Regis University	2		Lighting		
Regis University	3		Lighting		
Regis University	4		Heat Exchanger/ Recovery	Upgrade	
Regis University	5		Process Heating	Upgrade	
Regis University	6		Insulation		
Regis University	7		Motor Systems and VFD		
Regis University	8		Process Improvement	VFD	
Regis University	9		Envelope		
Regis University	10		Envelope		
Regis University	11		Envelope		
Regis University	12		Transportation		

AP Actions

Regis University	13		Boiler		
Regis University	14		Lighting		
Regis University	15		HVAC		
Regis University	16		HVAC		
Regis University	17		Alternative Energy		
Regis University	18		Heat Exchanger/ Recovery		
Regis University	19		HVAC		
RMC	1		Compressed Air		
RMC	2		Process Improvement	VFD	
RMC	3		Process Improvement		
RMC	4		Process Improvement		
SAE Circuits		Waste Elin	Recycling	Other Materials-General	3531
SAE Circuits		Waste Elin	Recycling	Liquid Waste-Miscellaneous	3514
SAE Circuits		Waste Elin	Recycling	Other Materials-General	3531
SAE Circuits		Waste Elin	PP	General-Removal of Contaminants	3312
SAE Circuits		Waste Elin	Recycling	Liquid Waste-Oil	3511
SAE Circuits		Industrial E	Fuel Switching	Fuel Switching-Alternate Fossil Fuel	2133
SAE Circuits		Industrial E	Fuel Switching	Fuel Switching-Alternate Fossil Fuel	2133
SAE Circuits		Industrial E	Heat Exchanger/ Recovery	Heat Recovery-Heat Recovery from Specific Equipment	2243
SAE Circuits		Industrial E	Fuel Switching	Fuel Switching-Alternate Fossil Fuel	2133
SAE Circuits		Industrial E	Motor Systems and VFD	Motors-Hardware	2412
SAE Circuits		Building an	Lighting	Hardware	2714
SAE Circuits		Building an	HVAC	Ventilation-General	2731
SAE Circuits		Waste Elin	Recycling	Solid Waste-General	3521

AP Actions

Saint Barnabas Medical Center		Industrial E	Energy Management Operations	Equipment Control-Equipment Automation	2623
Saint Barnabas Medical Center		Industrial E	Motor Systems and VFD	Motors-Hardware	2412
Saint Barnabas Medical Center		Building an	HVAC	Space Conditioning-Controls	2726
Saint Barnabas Medical Center		Industrial E	Energy Management Operations	Maintenance-General	2611
Saint Barnabas Medical Center		Industrial E	Energy Management Operations	Maintenance-General	2611
Saint Barnabas Medical Center		Industrial E	Steam System	Steam- Traps	2211
Saint Barnabas Medical Center		Waste Elin	Water Use	General-Removal of Contaminants	3312
Saint Barnabas Medical Center		Industrial E	Process Cooling	Cooling-Chillers and Refrigeration	2262
Saint Barnabas Medical Center		Industrial E	Energy Management Operations	Equipment Control-Equipment Use Reduction	2621
Saint Barnabas Medical Center		Building an	Lighting	Hardware	2714
Saint Barnabas Medical Center		Transporta	Transportation	General	5520
Sampsonite	1		PP	Waste Reduction	
Sampsonite	2		Lighting		
Sampsonite	3		Energy Management Operations		
Sampsonite	4		Energy Audit		
Sampsonite	5		PP	Waste Reduction	
Sampsonite	6		PP		
Sampsonite	7		PP		
Sampsonite	8		Lighting		
Sampsonite	9		Energy Management Operations		
SBT Automation		Waste Elin	Recycling	Other Materials-General	3531
SBT Automation		Corporate ,	PP	Audit	5231
SBT Automation		Corporate ,	Community/Supplier Outreach/Education	Supplier Outreach	5222

AP Actions

SBT Automation		Corporate .	PP	General	5234
SBT Automation		Other	PP	Paper	
SBT Automation		Other	PP	Paper	
SBT Automation		Building an	Office	Energy Efficient Equipment	5110
SBT Automation		Waste Elin	PP	Procedures-Product Specifications	3117
SBT Automation		Building an	Lighting	Controls	2713
SBT Automation		Building an	HVAC	Space Conditioning-Controls	2726
SBT Automation		Other	Envelope	None	
SBT Automation		Building an	Envelope	Building Envelope-Infiltration	2741
SBT Automation		Building an	HVAC	Space Conditioning-Maintenance	2721
SBT Automation		Corporate .	Community/Supplier Outreach/Education	Community Outreach	5221
SBT Automation		Waste Elin	Recycling	Procedures-Product Specifications	3117
SBT Automation		Waste Elin	Recycling	Other Materials-General	3531
SBT Automation		Waste Elin	Recycling	Other Materials-General	3531
SBT Automation		Building an	HVAC	Space Conditioning-Operation	2722
SBT Automation		Other	PP	Paper	
SBT Automation		Waste Elin	PP	Procedures-Product Specifications	3117

SBT Automation		Building an	Lighting	Operation	2712
SBT Automation		Waste Elir	Recycling	Other Materials- General	3531
Sun-Kist Dry Cleaners		Industrial E	Steam System	Steam- Leaks and Insulation	2213
Sun-Kist Dry Cleaners		Industrial E	Steam System	Steam- Traps	2211
Sun-Kist Dry Cleaners		Industrial E	Steam System	Steam- Condensate	2212
Sun-Kist Dry Cleaners		Building an	Lighting	Hardware	2714
Sun-Kist Dry Cleaners		Waste Elir	PP	Solvents- Use Reduction	3811
Total Petroleum Commerce Refinery		Industrial E	Heat Exchanger/ Recovery	Heat Recovery- Other Process Waste Heat	2244
Total Petroleum Commerce Refinery		Industrial E	Heat Exchanger/ Recovery	Heat Recovery- Other Process Waste Heat	2244
Total Petroleum Commerce Refinery		Industrial E	Boiler	Boilers- Operation	2121
Total Petroleum Commerce Refinery		Industrial E	Motor Systems and VFD	Motors- Hardware	2412
Total Petroleum Commerce Refinery		Building an	Lighting	Hardware	2714
Total Petroleum Commerce Refinery		Building an	HVAC	Space Conditioning- Hardware- Heating/Cooling	2723
Total Petroleum Commerce Refinery		Industrial E	Steam System	Steam- Leaks and Insulation	2213
Total Petroleum Commerce Refinery		Industrial E	Energy Management Operations	Transmission- Transformers	2351
Total Petroleum Commerce Refinery		Industrial E	Motor Systems and VFD	Motors- Hardware	2412
Total Petroleum Commerce Refinery		Industrial E	Process Cooling	Cooling- Cooling Towers	2261
Total Petroleum Commerce Refinery		Industrial E	Heat Exchanger/ Recovery	Heat Recovery- Heat Recovery from Specific Equipment	2243

AP Actions

Tri Valley Growers		Waste Elim	Recycling	Liquid Waste-Miscellaneous	3514
Tri Valley Growers		Waste Elim	Water Use	General-Material Concentration	3313
Valleylab	1		Lighting		
Valleylab	2		Lighting		
Valleylab	3		Lighting		
Valleylab	4		Boiler	Upgrade	
Valleylab	5		Envelope		
Valleylab	6		Lighting		
Valleylab	7		HVAC		
Valleylab	8		PP		
Valleylab	9		HVAC		
Valleylab	10		Energy Management Operations		
Valleylab	11		Compressed Air	Upgarde	
Weaver Potato Chip Company, Inc.			HVAC		
Weaver Potato Chip Company, Inc.			Compressed Air	repair leaks	
Weaver Potato Chip Company, Inc.			Water Use		
Weaver Potato Chip Company, Inc.			Compressed Air	outside air intake	
Weaver Potato Chip Company, Inc.			Lighting		
Weaver Potato Chip Company, Inc.			Water Use		
Westinghouse Motor Company			HVAC		
Westinghouse Motor Company			PP		
Westinghouse Motor Company			HVAC		
Westinghouse Motor Company			HVAC		
Westinghouse Motor Company			HVAC		
Westinghouse Motor Company			Office		
Westinghouse Motor Company			Motor Systems and VFD	VFD	
Westinghouse Motor Company			Energy Management Operations		
Westinghouse Motor Company			PP		
Westinghouse Motor Company			Lighting		

AP Actions

Westinghouse Motor Company			Office		
Westinghouse Motor Company			Office		
Westinghouse Motor Company			Envelope		
Westinghouse Motor Company			Lighting		
Westinghouse Motor Company			Lighting		
Westinghouse Motor Company			Process Cooling	Upgrade	
Westinghouse Motor Company			Transportation		
Westinghouse Motor Company			Energy Management Operations		
Westinghouse Motor Company			Process Improvement		
Westinghouse Motor Company			Recycling		
Westinghouse Motor Company			Recycling		
Westinghouse Motor Company			Recycling		
Westinghouse Motor Company			Recycling		
Westinghouse Motor Company			Process Heating	Upgade Ovens	
Weyerhaeuser Company		Corporate ,	Process Improvement	General	5234
Weyerhaeuser Company		Corporate ,	PP	Audit	5231
Weyerhaeuser Company		Corporate ,	Energy Tracking/Reporting	Teams	5212
Weyerhaeuser Company		Forestry	Forest Preservation/ Tree Planting	General	5310
Weyerhaeuser Company		Forestry	Forest Preservation/ Tree Planting	General	5310
Weyerhaeuser Company		Forestry	Forest Preservation/ Tree Planting	General	5320
Weyerhaeuser Company		Industrial E	Fuel Switching	Fuel Switching-Miscellaneous	2134
Weyerhaeuser Company		Industrial E	Process Heating	Furnaces, Ovens, and Directly Fired Operations-Maintenance	2113
Weyerhaeuser Company		Waste Elin	Process Improvement	Procedures-Miscellaneous	3119

AP Actions

Weyerhaeuser Company		Transporta	Transportation	Alternative Fuel Vehicles	5510
Weyerhaeuser Company		Transporta	Transportation	General	5520
Weyerhaeuser Company		Forestry	Forest Preservation/ Tree Planting	Tree Planting	5330
Weyerhaeuser Company		Industrial E	Motor Systems and VFD	Motors-Hardware	2412
Weyerhaeuser Company		Industrial E	Cogeneration	Cogeneration-General	2341
Weyerhaeuser Company		Industrial E	Heat Exchanger/ Recovery	Heat Recovery-Heat Recovery from Specific Equipment	2243
Weyerhaeuser Company		Forestry	Process Improvement	General	5320

AP Actions

Activity	Type		
Optimization of HVAC equipment and controls: air handling unit adjustments, preventative maintenance, exhaust reductions, ext.			
Lighting system upgrades: use motion detector switches, timers, lighting controls, reflective lighting fixtures			
Implement building envelop repairs: Seal roof, ducts, windows and wall opening to minimize infiltration			
Educate employees concerning energy conservation initiatives and encourage their participation to identify potential conservation opportunities			
Install automated fume hood sash controls in laboratories.			
Modify cogeneration engines to clean burn technology			
Sponsor employee commute-a-van program.			
Implement comprehensive solid waste recycling/reduction program for paper, cardboard, plastics, Styrofoam, metals, resins, pallets, surplus office supplies and equipment, etc.			
Sponsor local community environmental education programs.			
Schedule Climate Wise technical assistance site assessment.			
Schedule City of Austin water use/irrigation evaluation.			
Investigate alternatives for cooling water reuse for electron microscopes.			
Investigate potential reuse opportunities for tempered water supply for safety showers and eye wash stations.			
Evaluate and implement water conservation opportunities identified in the City of Austin audit.			
Optimize compressed air usage: for humidity control in environmental chambers.			
Eliminate employee use of portable space heaters.			
Replace bubblers in fountain courtyard with pavestone to conserve energy and water.			
Utilize alternative energy: experimental photovoltaic energy system installed in 1988. Energy from cells supplies power for parking garage.			
Minimize Leaks: Use of ultrasonic leak detector to find air leaks			
Minimize Leaks: Use of ultrasonic leak detector to find gas leaks and maintain steam traps.			
Improve HVAC controls: Install controls on heaters at loading docks.			
Establish preventative maintenance system for evaluation and replacement of exterior door weather stripping.			
Supplement electric heating to catalytic thermal oxidizer with steam.	Expanded		
Maintain steam traps throughout each applicable manufacturing and R&D facility.	Expanded		
Install motion detectors where appropriate.	Expanded		

AP Actions

Install energy efficient computers during computer upgrades.	Expanded		
Maintain chiller efficiency where applicable.	Expanded		
Maintain boiler efficiency where applicable.	Expanded		
Reuse treated waste water in cooling towers at Anasco and Hormigueros (Puerto Rico facilities).	Expanded		
Install ethylene oxide catalytic thermal oxidizer with exhaust gas heat recovery; discontinue water scrubber.	Expanded		
Continue shutdown of facilities during off-hours and weekends where possible.	Expanded		
Installation of a process cooling tower in place of using chilled water at Westport, Ireland.	New		
Insulate exposed steam lines at Westport, Ireland facility.	Expanded		
Install soft-start motors on two air handlers at Waco, Texas.	Expanded		
Install energy-efficient motors on bioscrubber and Silicone facility expansion project.	New		
Install baler at Westport, Ireland facility for recycled materials.	New		
Complete installation of isopropyl alcohol recycling unit at Anasco, Puerto Rico.	New		
Improve onsite treatment of waste water, reducing waste sent offsite for disposal.	New		
Continue to evaluate lighting retrofits per the Green Lights Programs.	Expanded		
Connect single fluid cooling and heating system to compounding vessels, use PLC controllers.	Expanded		
Install insulation on the oxidizer.	Expanded		

AP Actions

Community outreach. Boy Scouts/environmental awareness.	Accelerated		
Conduct annual governmental standards training, as well as training with first responders and on emergency procedures on all chemicals.	Completed		
Received Green Lights award.	Completed		
Replaced chemical line flushing from single line to multiple color coded lines, which resulted in a reduction of chemical waste disposal by 85%.	Completed		
Modified floors for chemical containment and collection.	Completed		
Use of parrot pickers instead of fork lifts.	Completed		
Community outreach. Create business coalition for area beautification, encourage residential waste reduction.	Accelerated		
Reduction of VOC's through ventilation system and vapor recovery improvements. Resulted in a reduction of 65%.	Completed		
Retrofitting xerox machines with more energy efficient models.	Expanded		
Recycle tote cleaning station.	Expanded		
Employee training. Responsible care committee, expanded quality plus training, MSDS product stewardship progam.	Completed		
General waste treatment and disposal: Chemical storage/labeling and color coding.	Expanded		
Recycle waste stream.	Expanded		
Retrofitting A/C units with new roof-mounted energy efficient models.	Expanded		
Spill prevention on trucks.	Expanded		
General waste treatment and disposal: Color coding for quality control.	Expanded		
Continue to plant trees in parking lot and around building. Removal of exotic plants and replacement with native species.	Expanded		
Retrofitting hose trays on trucks using color coding.	Expanded		

AP Actions

Replace current saw which generates dust to slitter which does not.	Accelerated	
Storage of chemicals in containers to hold less than 5-gallon containers for accident prevention.	Accelerated	
Upgraded hand trucks from two wheels to four to prevent slipping.	Completed	
Reduce single occupancy vehicles used by employees commuting to and from work in areas where employee commute programs are required by the Clean Air Act.	New	
Require business units and divisions which manage facilities to develop and implement 5-year energy management plans and goals.	New	
Continue to participate in the Energy Star Computers Program.		
Strengthen pollution prevention initiatives which will reduce emissions from its manufacturing processes.	Expanded	
Optimize savings on computer equipment through the utilization of monitor misers, office misers, and laser misers. Assure that each Energy Star feature is activated on computers and laser printers.		
A hot water boiler currently serves two shell and tube heat exchangers for our galvanizing process. Energy savings will be realized by going to more efficient plate and frame heat exchangers.	New	
A solvent distillation unit was installed to reclaim solvent and reduce the amount of hazardous waste generated and shipped from our facility.	Completed	
Air doors for the 2 high usage south facing truck doors will be installed for energy savings. It is estimated that the doors are open 60% of the time during production periods.	New	
Outside air will be piped to our air compressor intakes and air compressor leaks will be sealed for energy savings.	New	
Two enclosed paint gun washers will be installed to clean paint guns and associated lines. This will result in a reduction of solvent air emissions and a subsequent decrease in solvent usage.	New	
Existing lamps and magnetic ballasts that exist in some of the plant bays will be replaced with higher efficiency lamps and ballasts when replacement is needed to save energy.	New	
Installed a high solids paint system to reduce waste paint and VOC emissions. Rotary atomizers are used to electrostatically spray the paint on the metal fabricated products.	Completed	
We are continually upgrading our water treatment facility to improve water quality and reduce waste. A filter press was installed and reduced sludge generation by approximately 50%.	Completed	

AP Actions

A Beta System was installed to recycle waste sulfuric acid generated from our galvanizing process. This has significantly reduced the amount of waste shipped off-site.	Completed
Sample energy efficient lighting installations have been installed in our office. It is planned to expand this activity and replace all of the light fixtures in our 42,000 square foot office.	Expanded
Petroleum Naphtha solvent is currently used in 3 parts washers in the plant. This solvent will be replaced with a nonhazardous solvent to reduce the generation of hazardous waste.	New
Used free cooling during the winter.	Completed
Optimized energy efficiency in atrium building 200.	Expanded
Installed variable frequency drives on HVAC system.	Expanded
Phase 1. High efficiency lighting.	Completed
Electrical demand peak shaving.	Completed
Implemented site light "shut-off" practices.	Completed
Cooling coil condensate returned to water towers as make-up water.	Completed
Phased out 25 year-old boiler plant.	Completed
Installed new HVAC system.	Expanded
Installed power savers on photocopiers.	Completed
Installed site energy management systems.	Completed
Reduce number of light fixtures.	Expanded
Initiated cogeneration project, reducing power from the Utilities Board.	Expanded
Replaced lighting fixtures.	Completed
De-energized unused transformers.	Completed
Used BAS for control of mixed air temperature and supply air resets.	Completed
Combined building compressed air systems to optimize usage.	Completed

AP Actions

Cooling tower balancing to design flow rates.	Completed		
Initiated pilot lighting program. Installed occupancy sensors. Later expanded plant-wide.	Completed		
Installed computerized steam trap management system.	Completed		
Replaced air handlers with more energy-efficient models.	Completed		
Increased chiller optimization using BAS.	Completed		
Installed building automated system.	Completed		
Replaced chillers.	Expanded		
Increase thermal efficiency in cogeneration facility.	Expanded		
Improve gains of laboratory ventilation systems when non-occupied.	Expanded		
Increase efficiency of HVAC system in R & D.	Expanded		
Automation of four buildings.	Expanded		

Reduce energy costs by 3% per unit of production and reduce waste to our landfills by 30% by the year 2000.	Expanded		
Have our steam traps inspected by NC State in order to determine if we have any bad traps or leaks. Replace bad traps to improve boiler efficiencies.	New		
Reduce water usage and waste water by monitoring, tracking and controlling process water use.	New		
Reduce solid waste to the landfill, and other waste streams by 30% over the next three years. Plan to do this through reducing spills, quick clean-up and recycling usable beans back into the system.	Expanded		
Install power monitors, and implement a program to reduce peak electrical usage by 2.5%	Expanded		
Join motor challenge program and replace old motors with high effeciency motors when justifiable to reduce electrical usage.	New		
Conduct an energy audit and daily energy survey to assess our progress and take appropriate action to improve energy efficiencies.	Accelerated		
Install a new 60,000 lb/hr Nebraska boiler to replace the existing 20,000 lb/hr Cleaver Brooks boiler.	New		
Add additional desolventizing deck to DT for improved solvent removal and energy efficiency.	New		
Insulate boiler feedwater line for improved energy efficiencies.	Expanded		
Filmline waste heat recovery.	Expanded		
Auto starter coater #1 & #2 fan/blower start sequence to control peak surge.	New		
Purchasing energy efficient computers, monitors and printers having EPA Energy Star Logo as needed.	Expanded		
Install a more effective roof insulation (R value 7.14), roof reflective covering.	New		
Replace constant temperature thermostats with automatic thermostats- timer/set-back.	Expanded		
Efficient lighting, replacing flourescent lighting with HD lighting.	Expanded		

AP Actions

Institute a chiller maintenance program.	New		
Institute a steam trap maintenance program.	New		
Insulate steam and condensate main lines.	New		
Reducting air compressor exhaust to glue storage.	New		
Institute a compressed air maintenance program.	New		
Properly size replacement motors with high efficiency motors.	New		
Lighting control with motion sensors in outer buildings and office buildings.	New		
Coater #2 solvent heat recovery.	New		
Coater #2- Glue pumps/changing for cyclic to constant running.	Expanded		
Coater #3 extruder heating insulated/manage heat applied (Kw).	New		
Coater #3- reduct IR waste heat into pretunnel.	New		
Recirculate hot air into TDO section of filmline ovens.	New		
Filmline extruder heating/manage applied (Kw) to heating coils to most efficient means.	New		

AP Actions

CF & I has begun an initiative to conduct a chiller plant expansion of (2) 1000 ton absorption chillers.	New		
CF & I will select a "partner" to manage and optimize the use of natural gas, electricity, and other fuels.	New		
CF & I has selected a partner to focus on the utilization of chemicals in treatment of process water and water. The partner will ensure system optimization and continuous improvements and reductions of chemical use.	New		
Quantify our steps taken in energy conservation and water pollution prevention in order to see what savings have resulted from our experience and to determine the payback period for improvements and opportunities for further improvements.	New		
Set up scrap metal recycling program.	New		
Educated personnel to turn off unneeded lights.	New		
Educated personnel to turn down thermostats.			
Cleaned out accumulations of old, unidentified or useless chemicals and recycled them through the local environmental depot.	New		
Set up office recycling program.	New		
Set up hazardous waste storage for reuse and recycling.	New		
Extend useful life of solvents by filtration.	New		
Reduce evaporation of uncovered solvent tanks. Developed a plan for an enclosed chemical room to be built which will improve evaporation retardation.	New		

AP Actions

Recovery of metals from rinse water.	New		
Replace hazardous solvents in our stripping room with environmentally friendly chemicals wherever possible. Specifically, have replaced Methylene Chloride stripping solution with a safer, greener stripper which is performing beyond expectations.	New		
Upgrading of tumblers and closed-loop recycling of rinse water in the production room.	New		
Regular maintenance and tune-ups of natural gas heaters to decrease costs further.	New		
Install motion sensors for better control of lighting costs.	New		
Install programmed thermostats for better control of heating costs.	New		
Upgrade wall and ceiling insulation to R-30. Window caulking, weather stripping, entrance enclosures.	New		
Monitor improvements and savings in lighting by replacing older fluorescents with electric ballasts, reflectors and better job-specific lighting.	New		
Develop an ongoing motor replacement program, upgrading to premium efficiency motors.	New		
Sub meter electricity, gas and water usage to provide base data for cost-reduction savings and to quantify payback of investments.	New		
Segregate waste stream to reduce hauling, reducing air pollution.	New		
Implement recycling program to reduce/eliminate trash sent to landfill.	New		
Install energy information system to identify areas of inefficiency.	New		
Improve waste water treatment process to allow segregation of reusable materials (sugar).	New		
Continue to participate in Colorado Pollution Prevention Partnership, Pollution Prevention Advisory Board, Governor's Challenge Program via time spent and/or monitoring.	New		
Eliminated the use of TCA. Reduced major regulated waste stream.	Historic		
Reduced hazardous waste generation to the point of receiving small quantity generator status (from 184,000 lbs/yr to 60,152 lbs/yr).	Historic		
Steam turbine will generate electricity at container operations.	New		

AP Actions

Changed from landfilling of scrap wood (especially pallets) to chipping and composting (20,000 cubic yards/yr).	Historic		
Optimization of air compressor uses.	New		
Optimization of turbine liquifiers.	New		
Turn off cellar fans at night.	New		
Fluorescent lighting in aging cellars.	New		
Ensure that all heat tracing is functional and working efficiently.	Acclerated		
Continue participation in the EPA "Green Lights" Program. Re-lamp as required.	Expanded		
Preheat boiler feedwater using boiler stack heat.	New		
Use well water in lieu of city for vacuum seals and de-foaming spray balls.	New		
Seal roof/duct/window/wall openings to minimize infiltration.	New		
When replacing frequently used high hp motors, replace with high efficiency ones.	New		
Close off unused steam lines.	New		
Do computerized load shedding during six (6) cooling months using Energy Management System (250 KW).	New		
Perform semi-annual "open" boiler inspections.	New		
Install turbo-disk vs spray balls to minimize use of wash-out (hot) water.	Acclerated		
Establish a Central Climate Wise Committee and appropriate teams throughout the manufacturing facility.	New		
Public relations/signage for energy and waste reduction/recycling programs.	Expanded		
Perpetuate the existing steam trap program.	Acclerated		
Install variable speed control on main chilled water systems.	Acclerated		
Perpetuate and "fine tune" temperature control calibrations.	Acclerated		
Establish a formal "Climate Wise" policy.	New		
Implement monthly efficiency checks on all boilers.	New		
"Fine tune" the existing energy management system.	Accelerated		
Continue to track all utilities.	Accelerated		

AP Actions

Install recirculating chilled water system and identify any losses.	Accelerated		
Update and perpetuate the maintenance computerized PM System.	Accelerated		
Following company guidelines, maximize reuse/recycle programs to minimize waste (currently >=90%).	Acclerated		
Continue corporate "Shape Up Tours". Audit energy and waste programs.	Accelerated		
"Fine tune" all economizer cycles on all HVAC units. Check that all outside air settings are minimized.	Accelerated		
Conduct compressed air survey for leaks, bypasses, and misuse.	Expanded		
Maximize the shutdown of packaging equipment when not being utilized.	Expanded		
Maximize the use of reusable canvas bags, pallets, and bins to minimize the number of recycled items.	Expanded		
Increase the number of employees who car pool.	Expanded		
Re-gasket outside dampers to minimize outside air leakage.	Expanded		
Increase the amount of room occupancy sensors where feasible.	Expanded		
Continue pipe/duct/building insulation programs.	Expanded		
Conduct nitrogen use surveys for leaks and misuse.	Expanded		
"Fine tune" maintenance shutdown tours.	Accelerated		

AP Actions

Transportation efficiency activities: Compressed work schedules available to hourly employees, flex time schedules to avoid rush hour traffic.	Completed		
Retrofitted 80% of our facilities with "green lights." Savings per year of approximately $150,000.	Completed		
Community Outreach: Employees participate in community outreach programs such as "Beynanze."	Completed		
Packaging reduction: Packaging Task Force made up of different department representatives has reduced packaging material by approximately 500,000 pounds.	Completed		
Recycling program includes paper/cardboard (50% of the solid waste is recycled), aluminum, printer cartridges (over 400 unites are recycled each year), and wooden pallets (4 tons recycled each year).	Completed		
Active Environmental Committees made up of volunteer employees work on projects to raise awareness about environmental issues and identify opportunities for waste reduction projects.	Completed		
Installation of energy efficient refrigeration equipment in 1993.	Completed		
Chemical Exchange Program: Unused chemicals are redistributed to other departments. These chemicals are also donated to local colleges and universities. Currently pursuing possibilities to expand this program to include laboratory equipment/supplies.	Expanded		
Develop a procedure for extracting the printed circuit boards from instruments prior to disposal.	New		

AP Actions

Reduction of hazardous waste incineration practices. Exploring water treatment, metal recovery, and fuel blending.	New		
Continue to plant trees in parking lots and areas next to buildings for energy conservation. A FIU graduate student from the landscape architect program is involved in a project to strategically plant trees for energy conservation.	Expanded		
Expanded the required RCRA training to include local environmental issues such as ground water contamination.	New		
Initiate campaign to raise awareness about the advantages of using electronic mail, reducing paper consumption.	New		
Cafeteria/Break Room Waste Reduction Program: Employees given reusable mugs or incur additional expense if opt to use disposable cups. Condiments are available from serving dispensers instead of individual packets.	Completed		
Program designed to reduce biohazardous waste by proper segregation practices. Since its start, this program has reduced biohazardhous waste by approximately 100 tons/year.	Completed		
Convert from high solids baked enamel liquid paint to powder paint.	New		
Insulate the drying and curing oven.	New		
Monitor and repair any compressed air line leaks.	Expanded		
Duct in outside air for compressor intakes.	New		
Initiated use of large ceiling fan on north side of building to pull cool morning air into plant, thus reducing the need for factory air conditioning.	Completed		
Install automatic timelock thermostats to reduce space temperature.	New		
Reduce energy consumption in office	New		
Install high efficiency lighting	New		
Reduce convection heat losses from the bake ovens	New		

AP Actions

Process Cooling - install variable frequency drives on all chillers and booster pumps and test frequencers on compressors	New		
Electrical Power Management - Evaluate technologies for reduced KW consumption.	New		
HVAC - install an evaporative cooling system at one of our facilities	New		
Compressed Air Systems - minimize the run time of air compressors, identify air leaks by auditing the air system, and take action on recommendations.	New		
Recycling - become "Waste-Wise" partner	Expanded		
Waste Reduction - Assist food service contractor in planning, designing, and implementing a composting program at the Round Rock facilities.	New		
Water Heating Systems - insulate hot water tanks and pipes	New		
Mark plastics for recycling - 25% to eliminate plastic waste disposal.	New		
Building shell energy audit for complete Braker complex.	New		
Pallets-Reuse Program establish relationships with suppliers to provide reusable pallets for closed-loop exchange.	Expanded		
Motors - Join the Motor Challenge program and replace old motors on process equipment with high efficiency motors; Replace belts with notched v-belts.	New		
Energy efficiency-Apply Round Rock and Metric 12 sites as "Green Buildings" under the "Energy Star" program.	New		
Incorporate "Snap in" technology for ease of repair and upgrades - 25% savings on on-site repair time.	New		
Incorporate thin-wall technology for plastics - 20% savings on material.	New		
Work w/vendors to eliminate hazardous materials in products we manufacture.	New		
Green Product Design - 10% increase in Blue Angel sales in Germany.	New		
Conduct energy audits and develop recommendations to improve energy efficiency for our manufacturing and Round Rock Facilities	New		
Office paper: 1) reduce advertising mail; 2) recycled toner metrics; 3) reduce copies campaign.	New		
Investigate use of a reflective roof coating - conduct life cycle cost analysis.	New		
Water efficeincy- develop process for periodic monitoring of water useage throughout our sites.	New		
Public Transportation - Study: 1) subsidized passes; 2) pretax program; 3) shuttle buses; 4) van pool/car pool program; 5) telecommuting program; 6) biking/walking incentive program.	New		

AP Actions

Alternative work schedules - flex time, compressed work week-study.	New		
Transportation efficiency-perform feasibility study for the purchase of NGV.	New		
Office equipment- meet with business procurement group to initiate purchasing policy-buy only energy efficient products, recycled materials-spec meeting.	New		
Consolidate after-hours personnel into one area of building.	New		
Information campaign-environmentally conscious business practices including: 1) website-show energy consumption/savings; 2) recycling metrics on website; 3) personal coffee makers policy, etc. 4) new hire handbood; 5) scratch pad from used paper; (cont.)	New		
Lighting measures - Train security personnel to turn on/off lighting systems for after-hours use.	New		
Lighting measures - Daylight dimming controls in Metric 12-feasibility study.	New		
All lines of business to comply with Blue Angel, TCO '95 and ISO 14000/EMAS by the end of FY'99.	New		
Lighting measures - install occupancy sensors whre ROIC in greater than 20%.	New		
Lighting measures - join EPA Green Lights Program	New		
(continued) 4) HVAC belts/equipment tune-ups; 5) clean lamps/luminairs; 6) adjust water fountain temp.; 7) vehicle maintenance; 8) landscape water-saving.	New		
Convert existing manual preventative maintenance program to a computerized maintenance management system to capiture more energy saving efforts such as: 1) cleaning condensor coils; 2) Ongoing motor replacement; 3) HVAC equipment tampering; (continued)	New		
Landscaping - 1) Xeriscape Study; 2) Audit water sprinkler systems.	Expanded		
Solid waste reduction: 1) benchmark program metrics w/Balcones Recycling; 2) Reuse Program in manufacturing for packaging material, boxes.	New		
(continued) 6) save documents electronically; 7) minimize use of copiers; 8) proof documents on screen; 9) e-mail not paper; 10) public transportation-rideshare opportunities.	New		

Cardboard and paper recycling.			
Have an ongoing recycling program, which includes an in-house solvent recovery system. Recycle paint and reducers.	Expanded		
Recycle freon 12 and 134A.	Accelerated		
Replace fluorescent lighting with metal halide.	New		
Van delivery system with mobile phone for customer delivery.	Accelerated		
Installed more efficient paint spray guns which utilize a transfer rate of at least 70%.	Accelerated		
Installed a paint mixing computer to facilitate mixing small batches of paint so there is less hazardous materials released into the air.	Accelerated		
Use freez 12 for A/C installations due to the ozone friendly nature of the product.	New		
Install energy efficent A/C and heating in office area.	New		
Use of water wash paint booth for all paint operations has reduced the amount of pollutants emitted into the air by significant amounts.	Accelerated		

Have adopted the rule of using products with the least amounts of VOC's that will still accomplish the job to be done.	New		
Metal recycling.			
Improve insulation in shop area.	Expanded		
Develop ways to accurately measure, calculate, or predict greenhouse gas emissions at manufacturing plants. Also, will voluntarily report greenhouse emissions and use this information to establish a baseline for future target levels of GHG's.	New		
Measure and record energy efficiency on a site-by-site basis worldwide.	New		
Use appropriate technology to reduce nitrogen oxide generation when it has a positive impact on tropospheric ozone levels. Options include using technologies like dry NOx combustors, steam/water injection for industrial gas turbines, low NOx burners.	New		
Publish an environmental, health and safety progress report to communicate our performance to the public and key company stakeholders.			
Continue to search for CFC and HCFC alternatives and further develop the use of naturally occurring CO2 as a blowing agent substitute for other materials with higher global warming potential ratings.	Accelerated		
Include energy conservation as a program goal in the newly published "Dow Environmental Management Standard".	New		
Participation in the EPA's 30/50 program. Will continue where possible beyond goal of a 50% reduction in SARA-listed compounds. Will also evaluate options to set a new baseline for future emission levels.	30/50 Program, Expanded		
Eliminated CFCs from all plastic foam products.	Historic		
Eliminated emissions of SARA-listed compounds by 50.6%.	Historic		
Participate in EPA Motor Challenge program.	Motor Challenge, Expanded		
Promote insulation products that help reduce greenhouse gas emissions.	?		
Establish an energy management structure to review energy consumption on a plant to plant basis and create strategies to reduce global energy use.	Expanded		
Promote cogeneration. Where possible, energy generated during one chemical process is fed or recycled into another.	?		
Improved total energy efficiency by almost 25% by installing cogeneration facilities, replacing old plants with modern facilities and developing new operating technology.	Historic		
Report progress to EPA/DOE on energy-related goals of the Climate Wise program.	New		

AP Actions

Virtual elimination of CFC manufacturing for sales. Efforts under way to reduce emissions of CFC alternatives to levels below current CFC emissions.	?		
Monitor and evaluate performance levels as part of Dupont's Corporate Environmental Planning Process	?		
Set performance targets. (All actions reported in the pledge letter have quantifiable targets and timelines for achievement.)	?		
Reduce PFC emissions.	?		
Eliminate all nitrous oxide emissions.	?		
HFC-23 emissions will not exceed more than Dupont's committed share.	?		
Publish a corporate environmental policy or statement.	Expanded		
Establish an energy management structure.	?		
Install compact fluorescent light bulbs in office area lighting systems.	Accelerated		
Consider specifying all paper products as containing post-consumer recycled content.	Expanded		
Install weatherizing strips on office windows and doors.	New		
Provide environmental education for employees, such as posting various literature on bulletin boards, hosting an Earth/Environment Awareness Week, and discussing progress with employees monthly.	New		
Plant one tree per year for the next two years.	New		
Reduce kWh/month usage by installing timers on A/C units (completed 2/96, monitoring is on-going).	New		
Reduce single occupancy vehicle commuting.	New		
Eliminate the need for heat press adhesive substitute (implemented 7/23/96).	New		
Improve recycling by increasing the recycling of aluminum, mixed office paper, and cardboard by 50% from 1995, and exploring non-traditional reuse-recycling (i.e., ETS, toner cartridges, and tyvek suits).	Expanded		
Phase out office supplies consisting of virgin resources. Phase in office supples consisting of recyled materials.	New		
Sell 1120 Opgas unite; a product designed to reduce emissions and improve performance of carbureted vehicles.	New		
Examine the feasibility of alternative work schedules. Allow employees to commute during non-peak times; compressed work week, telecommuting.	New		

AP Actions

Hold training programs on the energy saver features of Macintosh computers.	New		
Initiate an incentive program to encourage employees to reduce air emissions by using alternative forms of transportation to get to work.	New		
Develop and maintain a recycling and composting program.	New		

AP Actions

Convert new 20,000 sq. ft. facility with energy efficient lighting.	New		
Improve overall energy efficiency throughout building.	New		
Converted facility (10,000 sq. ft.) with ETTA electronic ballasts and controls.	Completed		
Will be 100% toxic chemical-free, from cleaning chemicals in winery to bathrooms, glues, etc.	?		
Create recycling center constructed from 100% recycled materials. Center will recycle 100% of all waste materials that pass through the Fetzer operations.	?		
Construction will take on the challenge of analyzing each and every element from materials to human comforts to resource replacement.	?		
We will no longer use a capsule, and the label will be from recycled paper using safe, non-toxic inks.	?		
All transportation vehicles will be solar, electric, or natural gas.	?		
Will be 100% solar powered in all operations.	Expanded		
Increase efficiency of insulation, passive cooling and heating, and environmental control system (programmable controllers).	Expanded		
Implemented equipment changes to reduce energy consumption in winery operations. Will further reduce energy consumption at waste water ponds.	?		
Packages will be produced from 100% recycled material and non-toxic environmentally-safe inks. We will be the leader in state-of-the-art environmental design and implementation. The glass will be 100% recycled material.	?		
Implement Ford Motor Company's Total Waste Program. Use one of three Ford approved waste haulers for all waste, resulting in a cost savings of a min. of 5%/yr. for a min. of three years according to the terms of the contract.	New		

AP Actions

Collect scrap integrated circuit parts and circuit boards for precious metal reclaim shipment.	New		
Re-define solvent contaminated debris profile. If shipped in poly drums, this profile can become "recyclable," listed as a solid fuel.	New		
Replace lamps with Phillips Alto fluorescent lamps, which will reduce hazardous waste disposal costs and energy costs (cost will increase by $.18/lamp, but savings from disposal are expected to be $1.50/lamp). Current stock will be returned for credit.	New		
Install high efficiency replacement motors. This process has already begun and will be an on-going activity; when current motors need to be replaced, they will be replaced with high efficiency electric motors.	Expanded		
Install high efficiency lighting on a group-replacement basis. This project is currently being researched, with cost estimates due 5/20/97.	New		
A newly appointed Energy Operations Manger will accelerate the implementation of a benchmarking project designed to identify the 10 least efficient facilities, audit their operations, and implement the identified actions.			
Launch Green Lights in the truck and Saturn facilities. Program will begin in these two divisions and may be expanded corporate-wide.			
Work together with the DOE National Laboratories to identify cost effective energy efficiency and pollution prevention actions.			
Under the new Energy Operations Team, GM will accelerate the Powerhouse Evaluation Study that is scheduled to involve 50 facilities in 1995. The study seeks to identify opportunities for shutting down or converting plant boilers to become more efficient.			
Continue to evaluate the feasibility of cogeneration facilities to provide the efficient generation of electricity and steam. Continue to investigate the option to provide an overall net reduction in emissions when compared to generating separately.			
Increasing use of videoconferencing to conduct meetings among domestic facilities as well as with GM operations in other countries to reduce travel.			
Committed over the long term to making substantial investments to improve the fuel efficiency of its vehicles.			
Conducts annual energy competition to allow energy improvement projects implemented throughout the year to be recognized with plaques and satellite TV broadcast. Project ideas are also shared with other facilities through internal written communications.			
Launch Supplier Outreach Program to involve GM supply companies in energy efficiency initiatives such as those that GM is conducting. This program will begin with GM's participation in a workshop in New York August, 1995.			

AP Actions

Joined with the Nature Conservancy and committed to spend $5 million over five years to preserve land and water ecosystems and thus increase carbon sequestration potential in North America, South America, and the Pacific.			
Involved with the Conservation Fund, which includes a committment to help fund an environmental training institute.			
Became the first Fortune 500 company to endorse the CERES Principles.			
Combined Environmental and Energy Operations to more effectively translate the GM Environmental Principles into strategies and policies for the Corporation to achieve its concrete improvements.			
Participate in the EPA Motor Challenge Program.			
Established an internal pollution prevention initiative called WE CARE.			
Launched ODC Phaseout Program to reduce emissions of ODCs.			
Member of the President's Council on Sustainable Development.			
Member of the Clinton Administration's Policy Dialogue Committee To Develop Options for Reducing Greenhouse Gas Emissions from Personal Motor Vehicles.			
Each North American facility compiles and reports to a central database their monthly energy usage for each fuel. This allows each facility to track their performance and to benchmark against other GM units.			
Sponsors annual "Green Day" workshop for engineers, divisional representatives and suppliers. The intent is to increase awareness of the opportunities and the need to design vehicles for recycling.			
Participation in the EPA's 30/50 Industrial Toxics Project. Focus is on chlorinated solvents, although reductions have been realized in all 17 solvents.			
Participation in the "CONEG Challenge", a voluntary packaging waste reduction program. Committed to meet or exceed a 15% packaging waste reduction goal by 1996 using a combination of packaging source reduction, reuse, recycling, and recycled content.			
Participation in the EPA Waste Wi$e Program.			
Published its first GM Environmental Report in 1994 to foster public accountability. This annual accounting of our environmental performance discusses the progress and challenges of environmental managment at GM.			
Capture energy savings projects such as an improved A.F.E. system. Put energy coordinators at site.	New		

AP Actions

Add training programs in energy efficiency for operators and SUP's.	New		
Selected added instrumentation; boilers and other targeted processes.	New		
Increase employee involvement in energy efficiency programs, create energy "teams".	New		
Join available DSM programs.	New		
Implement electric lighting efficiency programs.	New		
Increase carbon sequestration by reducing waste wood to landfills, fuel switching.	New		
Complete analysis of transportation mileage savings through containerboard trading, pulp trading, backhauling plans, freight savings, and switching media.	New		
Add energy data collection quality control analysis to present energy report. Consider the transportation element.	New		
Energy reporting vis a vis Standards Progress Report. Sites performances.	New		
80% decrease in VOCs from internal printing operations achieved in 1993, leading to significantly improved environmental health and safety.	Completed		
15% decrease by 1995 and 6% decrease between 1995 and 2000 in energy consumption.	Expanded		
50% decrease by 1995 and 86% decrease between 1995 and 2000 in hazardous waste disposal.	Expanded		
70% decrease by 1995 and 75% decrease between 1995 and 2000 in solid waste disposal.	Expanded		
Complete our Production Demonstration Unit (PDU).	Expanded		
Increase manufacturing capability for our reverse osmosis/ultrafiltration units.	Expanded		
Plastic egg flats are used for shipment and storage of eggs, and must be washed after each use and then must be dried before returning to the layer houses. Exhaust air from the air compressors is ducted into a room where it is used to dry the egg flats.	New		
Ice water lines are also insulated.			
Frozen chicken meat is held in a freezer storage room at about 20 degrees farenheit. In 1995, this room was lined with insulated metal panels to reduce cooling losses.	New		

AP Actions

In 1995, a portion of the plant was converted from processing egg white to processing chicken meat. Rooms renovated at that time had high efficiency lighting installed.	New		
Steam lines throughout the plant are insulated. Ice water lines are also insulated.	New		
Non-waxed cardboard boxes are recycled. Waxed cardboard boxes, used for frozen meat shipment, are not recycled; alternate packing materials or other recycle options are being considered.	New		
Climate Wise has recommended high efficiency motors and replacement of V-belt drives. On a replacement/renovation basis over the next three years, the plant will convert over to these energy saving recommendations.	New		
Boiler air-fuel ratio has been adjusted by our service company to provide 3% excess oxygen at high fire.	New		
HF has operated two spray dryers equipped with waste heat recovery for many years. In 1993, a plant expansion included a new large spray dryer for egg white, installed with waste heat recovery, reducing the energy requirement by over 20%.	Expanded		
In 1996, the Nebraska Dept. of Environmental Quality authorized land application of egg shells as a fertilizer. As a result, 50 tons/week of egg shells have been diverted from land-filling.	New		
Cooling water for ammonia compressors is now being reused through cooling towers, resulting in a significant reduction in water use and wastewater volume.	New		
Operating procedures for the triple tube heat exchanger have been changed, resulting in a savings of over 800,000 gallons/year of water.	New		
In 1995, a portion of the plant was converted from processing egg white to processing chicken meat. New equipment was installed with high efficiency motors.			
Climate Wise has recommended high efficiency lighting. On a replacement/renovation basis over the next three years, the plant will convert over to this energy saving recommendation.			
Condensate lines throughout the plant are insulated.			
Air compressor intakes will be piped to bring in filtered ambient air to improve air compressor efficiency.	New		
Developed recycling program for 24 different materials that diverts 75% of HP waste from landfill. This reduces HP waste to landfill by approximately 3,200 tons/year.	Expanded		
Replace three water pump motors on boilers with high efficiency variable speed drives (VSD) motors.	Expanded		
Replace 220-ton and 440-ton chiller with high efficiency 560 R 123 ton chiller.	Expanded		

AP Actions

Replace 500-ton .... chiller with high efficiency 600-ton R 123 chiller.	Expanded		
Add 600-ton R 123 high efficiency chiller.	Expanded		
Replace two water pump motors with high efficiency VSD motors.	Expanded		
Add five VSD motors.	Expanded		
Replace magnetic ballasts with electronic ballast lights throughout plant.	Expanded		
Replace T12 fluorescent tubes with T8 tubes throughout plant.	Expanded		
Develop program to encourage office employees to turn off computer monitors and desktop lights in evenings and weekends.	New		
Develop waste prevention program to reduce landfill waste including: reusable cafeteria dishware, two-sided photocopying, reusable corrugated and plastic shipping containers.	Expanded		
Establish program to encourage employees to use alternative commute modes by offering rideshare parking and matching, transit subsidy, bike ammenities, etc.	Expanded		
Install more efficient Maxicom landscape watering system that measures local humidity and weather conditions before watering.	New		
Established program to turn off office lighting in evenings and weekends.	Expanded		
Lighting retrofit for Green Lights program.	New		
Replace existing steam-heated board dryers with direct-fired dryers, resulting in 20-40% energy reductions and emissions reductions.	New		
Cleaning of recycled waste paper to allow increased recycling percentage including energy savings.	New		
Improve site load factor for electricity electricity use. Target for annual average load factor is 80 %.			
Voluntarily ea			
Educate and create awareness about environmental best practices.			
Explore/pursue to install Kelmas Lightiing System after mthe system is UL certified at those U.S. sites where it is business justified.			
Continue installation of efficient lighting and equipment (including variable frequency drives) as opprtunities arise.			
Implement exhaust reduction project at appropriate sites.			
Improve enrgy efficiency in the design of processes and facilities.			
Explore for opportunities to implement cold storage/free cooling projects at appropriate sites.			

AP Actions

Monitor recycling non-hazardous waste each quarter. (The goal is based on a 2-tier approach i.e. 50% or 67% by weight).			
Monitor energy use, cost and conservation data each quarter.			
Implement reheat energy reduction project at appropriate sites.			
Monitor hazardous waste generated relative to production volumes each quarter.			
Vary temperature and humidity set points (including clean rooms) at those sites when appropriate.			
Participate in the Green Lights program.	Accelerated		
Reduce office waste by 50%.	New		
Participate in the Waste Wi$e program.	Accelerated		
Participate in the EPA Motor Challenge Program.	New		
Reduce production waste by 50% for non-hazardous waste and 10% for hazardous waste.	New		
Conduct our Energy Awareness Week in October of each year to heighten the awareness of energy usage and reduction opportunities for the employees at home and in the workplace.	?		
Conduct Earth Day in April of each year.	?		
Eliminate the use of CFCs in our products and processes.	New		
Eliminate the use of CFCs in refrigeration/chilling equipment (units of less than 5 tons exempt).	New		

AP Actions

Plan to install anaerobic and aerobic reactors to reduce wastewater COD and BOD prior to discharging to municipal sewer.			
Install micromotion mass flow meters and densitometers. This will allow for in-line blending, which will provide significant reduction in energy consumption compared with the present method of batch blending.			
Project to reclaim contaminated sugar from explosion at Scotts Bluff Sugar Refinery.			
Investigating ways to separate vegetable oil from alcohol and chloroform so oil can be sent to tallow and soap manufacturers instead of disposing as hazardous waste.			
Will replace hazardous chemicals presently used for COD analysis with environmentally benign chemicals.			

AP Actions

Create a Climate Wise management task force to help define and coordinate implementation issues within Martin Marietta-owned facilities. (This pledge is exclusive of government-owned contractor-operated facilities.)	New		
Create an energy conservation awareness campaign directed at employees, including their participation through an employee suggestion program.	New		
Assessment and evaluation of individual business unit opportunities for improved energy efficiency and reduced consumption. (These assessments will be performed either in-house or with the help of a consultant.)	New		
Prioritization of opportunities based on energy savings, emission reductions, cost and potential payback period.	New		
Completion of action plans for each operating organization which establish goals, reporting metrics and an implementation timetable.	New		
Identification of emission reductions, achieved through 1994 using 1990 as a baseline year, from those corporate-wide programs and operating unit actions already underway.	New		
Report to the joint DOE/EPA Project office results-to-date from the Climate Wise action programs in place, establish a comprehensive Martin Marietta action plan, commit to corporate-wide emission reduction targets for 1995 and out-years.	New		
Radiant heaters are regulated by set-back controllers which are enclosed in tamper-proof housings.			
All new computers are to have "Energy Star" designation. 20% of the office computers now have the designation.	?		
Warm exhaust from the compressor is vented outside to minimize excess waste heat during summer months.			
VOC contaminated rags are processed by an approved service and are returned for reuse.	?		
Using California compliant, high-velocity, low-pressure paint guns in all paint operations.	?		
All "used" solvent products are re-distilled for reuse.	?		
All CFCs have been eliminated from our products and processes.	?		
Sub-contractors have certified the elimination of CFC usage.	?		
Energy consumption for office lighting has been reduced by 50%. Installation of high efficiency fluorescent tubes which require two, as opposed to four, tubes; and one, as opposed to two, ballasts.	?		
Emergency exit sign energy consumption has been reduced by 80%. Installation of 7 watt fluorescent as opposed to 40 watt incandescent lights.	?		

AP Actions

Reduced the use of solvent borne coatings in our operations to the point that 97% of the materials used are water-borne or powder coat products.	?		
Intend to replace an additional 20% of our pallets with those made of recyclable plastic.	?		
All cardboard and office paper is recycled.	?		
In conjunction with Colorado State University's Energy Assessment Program and the US DOE, we will work to develop a cost-effective, closed-loop rinse system in our metal pre-paint processing area.	?		
Paint products contain no heavy metals.	?		
Office heating and cooling are controlled by set-back thermostats.	?		
Intend to pursue enhanced insulation of heated processing tanks and large shipping doors.	?		
We have worked with our shipping box and paper distributor who now provides boxes which average 20% recycled material, craft paper which contains 40% recycled material, and foam products containing 10% recycled material.	?		
2-30 hp compressors and 1-5 hp compressor have been replaced with a single 50 hp compressor which uses an electric monitoring controller and synthetic lubricants.	?		
A normally unoccupied receiving area is no longer heated or cooled; the entrance is blocked by a strip door. The energy savings should result in a 6% savings on the manufacturing area heating and cooling costs.	?		
A second, small oven has been installed to cure silk screen print rather than using the large paint cure oven. Fuel gas savings are approximately 15%.	?		
Manufacturing air conditioning has been upgraded to use units which are individually thermostat controlled. Units use the econo-miser feature and additional fan exhausting is used when outside air temperature drops below the thermostat set-point.	?		
Radiant heating is used in the manufacturing areas.	?		
All metal scrap and sanding fines are recycled.	?		

AP Actions

Reuse and recycle wooden pallets.	New		
Ammonia recovery by reverse osmosis separation.	New		
Collect environmental benchmarking data from industry association (IPC?), local high-tech firms, and other sources of similar data.	New		
Continue IBD 14000 program development, including identification of significant environmental aspects, targets, and objectives. Pursue certification to IBD 14001 standard.	Accelerated		
Reduce the number of single-occupant vehicle employee commute trips by 10%.	Accelarated		
Conduct an electricity use survey and evaluate the installation of submeters.	New		
Continue water use data collection and savings documentation (relative to CY 1995).	Expanded		
Collection of in-house waste paper for recycling. A yearly average to date is 45,000 lbs.	Completed		
Installed new chiller, cooling tower, and primary/secondary pumping. System to save in electrical energy costs from upgrade in efficiency.	New		
Purchased new exit lighting fixtures to reduce energy cost and maintenance labor costs.	New		
Perform extensive maintenance on chiller to improve efficiency and eliminate refrigerant losses through non-condensible gas purge systems.	Expanded		
Improve maintenance, calibration, operational reliability of HVAC control systems to assure building of appropriate ventilation and excellent indoor air quality.	Expanded		
Installed evaporative process to save energy and provide cooling comfort.	New		
Collection of in-house aluminum soft drink containers for recycling. A yearly average to date is 600 lbs.	Completed		
Performed boiler repairs to refractory and upgraded boiler burner controls for improved boiler burner efficiency.	Expanded		
Improved insulation to building.	New		
Install new electrical fluorescent light ballasts and T8 energy saving bulbs in each of 2,800 fixtures.	New		
MRI is an initiative member of the Kansas City Buy`Recycle Coalition, which is an organization that promotes the purchasing of recycled material. MRI's representative is the manager of our procurement department.	New		

• AP Actions

A computerized chemicals inventory information and tracking system has been designed, which will afford optimization of the quantity of chemicals ordered for use on our numerous and diversified projects.	Completed		
Purchase and utilize additional machine tool coolant recycling equipment in plant machine shop to reduce amount of cutting tool fluid shipped offsite.	Expanded		
Investigate the installation of a low pressure blower to provide agitation for rinse tanks in plating shop.	New		
Install a cover to close a hole in main drying oven to reduce heat infiltration in paint shop.	New		
Investigate the feasibility of converting existing electric motors with high efficiency motors as they wear out, adding this review as part of the preventative maintenance program of the company.	New		
Continue and increase cardboard recycling activity to 75% of generated amounts.	Expanded		
Investigate and install manual flow reducers or flow meters in rinse tanks in plate shop to reduce water flow.	New		
Convert batch paint booth from liquied high solids paint process to powder coat process.	Expanded		
Complete surveys and retrofit, as economically feasible, lighting in all corporate facilities.	Accelerated		
Purchase an oil separtor/filtering device on MC86 to recirculate and reuse machine tool coolant, prolonging coolant life.			
Purchase and install a solvent still to decant lacquer thinner for reuse in paint gun cleaning operation.			
Plumb 5 stage washer to counterflow 3 rinses down to a single rinse.			
Increase recycling program for office paper and implement program to reduce paper consumption in office by 25%.	Expanded		
Reduce paint wastes 50% by improved process and conversion to powder coat.	Expanded		
Assess and implement, if feasible, ducting intakes to the plant air compressors to outside air supply.	New		
Convert shipping foam to a non CFC containing subssitute. Eliminate CFC from aerosol containers and refrigerant systems of MTI manufactured products.			
Electricity Conservation-Fab Support: Optimize factory air recirculation flow rates and optimize exhaust systems.	New		
Off-Site Electricity Conservation-Raw Material Suppliers and Waste Receivers: Production and surface water re-use projects, and solid waste recycling.	Expanded		
Electricity Conservation-Production Tools: Develoop motor replacement program to upgrade motors, optimize pump operation, participate in Sematach tool exhaust reduction study, and address energy conservation issues during tool design.	New		

AP Actions

(continued) Re-engineer pipe networks and ductwork to reduce pressure drop and theraml losses; Insulate steam lines and repair faulty insulation; Install/repair insulation on condensate lines; Clean steam coils & processing tanks.	Expanded		
Electricity Conservation-Central Plant: Improve efficiency of air cooling systems; install VFD on high pressure pumps used in ultra-pure water production; Reduce hot water temperature below inefficient levels; Upgrade chillers; (continued)	Expanded		
Natural Gas Conservation-Fab Support: Preventative maintenance of regenerative thermal oxidizer and rotary concentrator oxidizer systems.	Expanded		
Electricity Conservation-Non-Production Site Buildings: Lighting upgrades including efficient lighting layouts, installation of occupency sensors, pho'sensors and fluorescent systems with electronic ballasts.	Expanded		
Natural Gas Conservation-Central Plant: Preventative maintenance and optimization of boilers	Expanded		
Motorola commits to implement cost-effective measures that will improve company productivity & profitability as well as reduce emissions. This plan represent the Ed Sluestein and Oak Hill sites in Austin, Texas.	Expanded		
Recycling of silver fixer solution.	Completed		
Install occupancy sensors in low use areas.	New		
Started a lead recycling program for all lead "pigs" used to shield low-level isotopes during shipment.	Completed		
Initiated a low-level "decay-in-storage" program to reduce the amount of low-level waste being sent out to radioactive waste facilities.	Completed		
Expand recycling program to include plastic tip boxes, plastic bottles, and glass chemical bottles.	Expanded		
Substitution of mercury thermometers with alcohol thermometers.	Completed		
Elimination of chromic acid for glassware washing.	Completed		
Investigate and implement the use of micro-base HPLC columns in operation where feasible as to reduce volume of hazardous materials, used and waste generated.	New		
Improve chemical inventory management system and re-distribution system to redu~e waste and unnecessary purchases.	Expanded		
Replace exit light lamps with energy efficient bulbs as bulb replacement becomes necessary.	New		

AP Actions

Replace existing lighting/ballast with energy efficient products in new expansion. Install occupancy sensors in low use areas.	New
Initiated paper, glass, and aluminum can recycling.	Completed
Initiated exposed x-ray film recycling.	Completed
Implement use of non-hazardous coil-cleaning and parts-cleaning solutions.	New
Aluminum can and bottle recycling.	Completed
Recycling of business sheets.	Historic
Newspaper recycling.	Expanded
Install an economizer on a 120,000 lb/hr boiler.	New
Install on end liners #1, 2, 3, 4, & 5 a system to use A O ea/gallon sealing compound.	Expanded
Switch to a 0 ea/gal. VOC end sealing compound.	Completed
Install low NOx burners in 3 boilers.	Completed
Pacific Energy Systems will encourage its employees to double-side photocopies to the extent it is feasible.	New
Pacific Energy Systems will maintain a tray of photocopier paper with the maximum feasible recycled content which will be used whenever feasible.	New
Pacific Energy Systems will review its progress on its action plan and will evaluate potential improvements in the plan at least once a year.	New
Pacific Energy Systems will encourage voluntary bicycle riding as an alternative to driving to work and will consider telecommuting and alternative work schedules on a case-by-case basis.	New
Pacific Energy Systems will review the recycled content of its notepad paper and will make available to staff paper with the maximum feasible recycled content.	New
Pacific Energy Systems will introduce to its clients and potential clients federal and state programs designed to mitigate greenhouse gas emissions to the extent consistent with the client's objectives.	New

AP Actions

Pacific Energy Systems will expand its recycling of cans and bottles disposed in the office.	Expanded
Pacific Energy Systems will become an industry partner in the EPA's Landfill Methane Outreach Program and will consider participation in the Coalbed Methane Outreach Program.	New
Evaluate transportation methods to airport. Combine and schedule accordingly to reduce the number of employee trips to the airport.	New
Evaluate and improve the use of building lighting through maintenance.	Accelerated
Calculate and reduce employee commute and business trips and evaluate further through video conferencing, telecommuting, and other transportation.	Expanded
Examine computer products to include in our recycling efforts.	New
Research and purchase recycled cafeteria utensils and office supplies for both internal and external uses.	Expanded
Document water savings from building's efficient design features.	Accelerated
Document energy savings from building's efficient design features.	Accelerated
Lighting retrofits: Energy Savings Performance Contract (ESPC) for Hanford and PNNL will potentially fund lighting retrofits in the 320, 325, 326, 331, and 337 buildings.	New
Encourage carpooling. Remind staff about available bikes and access to DOE vehicles.	New
Encourage staff to practice affirmative procurement, such as to track purchases (where possible) and increase communications.	Expanded
Used oil recycling.	Completed
Heat recovery capacity: ESPC for Hanford and PNNL will potentially fund heat recovery capacity upgrades in the 320 and 325 buildings.	New
Electronic time reporting.	Completed
PNNL's Operating Contractor, Battelle Memorial Institute is a member of Waste Wi$e.	New
PNNL's Operating Contractor, Battelle Memorial Institute is a member of Responsible Care, a voluntary DOE program through MOU with the Chemical Manufacturers Association. It is an environmental, safety and health performance improvement initiative.	New

AP Actions

Process wastewater from 325 Lab pump; replaced liquidring vacuum Lab pumps with new vacuum pumps.	Completed
Toner cartridge recycling.	Completed
Gell cell/lead acid batteries recycling.	Completed
Office products recycling program (white paper, corrugated cardboard, mixed paper, glass, plastic, tin, and aluminum).	Completed
Computer software and documentation recycling.	Completed
Solvent recycling (Formaldehyde, Xylene).	Completed
Encourage staff to turn off equipment such as computers and laboratory and office equipment, and lights in offices, kitchens, bathrooms, meeting rooms, etc.	New
Exhaust air heat recovery: ESPC and PNNL will potentially fund exhaust air heat recovery system upgrades in the 326 and 331 buildings.	New
Reuse of cooling system effluent in LSL II building.	Completed
Hot steam condensate collected inside the expanders is captured and recycled back to the boiler, significantly reducing energy usage and costs.	
Replaced three expanders with more modern equipment that is 40% more efficient. Capacity was increased from six truckloads/day to 7.5 truckloads/day.	
We recently installed 3 new AHU and connected them to the Lanlis GYR Energy Management Computer.	Expanded
Formed "Watts 'R' Game" TQM energy conservation team.	Completed
Replaced 72-inch diameter oversized boiler masonry chimney with two 24-inch metal stacks.	Completed
Partnered with local energy supplier, Wisconsin Power & Light.	Completed
Educated all 600 Arrow Park employees in basic home energy conservation techniques.	Completed
Replaced 1,100 fluorescent core and coil ballasts with electronic ballasts.	Completed
Replaced open condensate deaeration system with inline steam injection nozzle and downsized 2,000-gallon deaerator tank to 800-gallon tank.	Completed
Continue conversion to T8 fluorescent bulbs and fixtures.	
Use ultrasonic leak detection equipment to identify and repair leaks in compressed air system.	New

AP Actions

Complete conversion from central heating and cooling to roof top units.	New		
Replaced inefficient 150 hp air compressor with two 100 hp energy efficient units with energy saving motors.	Completed		
Replaced 15.6 million BTU input fuel oil burner with computer controlled 10.7 million BTU input natural gas burner, allowing the removal of a 39 year-old, 30,000-gallon underground fuel oil tank.	Completed		
Installed mechanical oil mist extraction system with clean air returned to building, solving oil mist problem and eliminating two 6,000 cfm exhaust fans.	Completed		
Modified open loop cooling system to utilize thermal value of recovery well water to cool 19 plastic injection molding machines.	Completed		
Survey our major vendors to see exactly what their practices are in applicable areas.	New		
Call companies who send us inappropriate catalogs and mailings and ask to be removed from lists; send in name to Direct Marketing Association to be removed from lists.	New		
Keep mailings lists current by asking people on each newsletter to tell us if they don't want to be on mailing list and annually purging names not active for 2 years.	New		
Reduce number of new 8.5x11 sheets used for non-essential reports, proofs, etc. by 75%.	New		
Recycling of all petroleum-based solvents and parts cleaning solution.	Completed		
Recycling of all mercury-containing lamps, ballasts, etc.	Completed		
Recycling of cutting oils and used motor oil.	Completed		
Corrugated cardboard recycling.	Completed		
Recycling of all metal and metal derived scrap. Steel drum recycling.	Completed		
Reduce consumption of electricity, gas and water. Gas consumption from boilers electricity consumption from an electrical foundry furnace and industrial machinery.			
Recycling of bronze grinding sand, wheelbrator sand bronze sweeping.	Completed		
Recycling of fiber drums, plastic buckets, pails and pans.	Completed		

AP Actions

Elimination/reduction of the solvents used in the conductor 1 process, with the exception of the isopropyl alcohol used for the drying process. This project should result in the complete elimination of solvents in this process.	New		
Elimination/reduction of solvents used in the conductor 2 process. Presently researching alternative, less volatile solvents to use in place of acetone and isopropyl alcohol, resulting in the elimination of acetone and a 50% reduction in the alcohol.	Expanded		
Replace present panel drying process with a process that uses 10% of the isopropyl alcohol we now use. This is being undertaken with new equipment that is just now coming onto the market.	Expanded		
Installation of direct digital controls on our HVAC system. This is calculated to reduce our overall energy usage by about 15%.	New		
Installation of a DI water recycling system.	New		
Continue to implement Polaroid's energy and enviroment policies that were developed in 1977, and reafirmed with the endorsement of the CERES Principles in 1994.	Expanded		
Provide training in "Best Design Practices" for R&D staff using Design for Environment (DEF) principles and tools which will be part of a new product development process. DEF includes environmental and energy parameters.	New		
Initiate a comprehensive Eco-Efficiency project in W5 to examine a new process and make technological and operational changes that will optimize energy, environmental and productivity.	New		
Intitiate a study to burn VOC's in gas turbine which will co-generate electricity and provide heat recovery at the Norwood site.	New		
Install new chiller and upgrade cooling tower at Polariod's reservoir facility.	New		
Complete Green Lights program started in 1991 as a charter memeber. Finish/update buildings W7, W4, Nor1, and NB 1-5. Completion of projects dependent on local utility rebate programs.	Expanded		
Participate in Integrated Resource Management (IRM) program with Boston Edison to reduce electrical energy usage at the Waltham, Needham and Newton facilities.	New		
Complete corporate energy audit and establish 5 year energy plan based on findings. Plan would inhance energy mgmt. capability and result in conservation projects consistent with company's policy	New		
Optimize power plant at New Bedford, including boiler management system, new cooling tower, new steam driven water chiller, electric driven glycol chiller and power factor correction.	New		

AP Actions

In 1996, the Corporate Energy Council was instituted to focus on energy conservation & cost containment and to establish a five year energy strategy. The council includes a cross-functional team of mgrs from Polaroid's domestic facilitites.	New		
Continue to implement Energy Star building program initiatives, including air handling system improvements. 1997 projects include our W4 and W5 facilities.	Expanded		
Commence the planning and organizing of the Green Lights Program- setting goals, organizing staff, leading towards conducting lighting surveys and evaluations throughout the facilities.	New		
Waste Wise - Sign pledge agreement and design a plan to expand the collection of recyclable materials in coordination with Puerto Rico solid waste policies.	Expanded		
WAVE - Identify significant water saving opportunities and document into an action plan.	Expanded		
Develop a detailed list of eligible facilities and their pertinent statistics to facilitate conducting a lighting survey.	New		
Install emergency low voltage exit signs as required.	Expanded		
Design energy-efficiency into new building construction, insulation, lighting, and mechanical systems.	?		
Recover waste heat by making use of the hot water created in water-cooled mechanical systems.	?		
Investigate possible conversion of part or all of our fleets of vehicles to alternative vehicles.	?		

AP Actions

Currently in the process of engineering a closed-loop ink jet system that captures 80 to 90% of solvent vapor and condenses it for reuse. The system cuts ink and solvent use in half, and is projected to save a min. of 2.31 trillion BTUs by the year 2010.	?			
Develop brownfield site for new operating facility.	New			
Reduce consumption of raw materials such as paper and ink, and recycle where consumption cannot be avoided.	?			
Maintain own tree farm to take in excess carbon in the environment.	?			
EPA Green Lights Program- retrofitting of lighting fixtures with more efficient technology.	Accelerated			
Participate in utility companies' rebate programs.	?			
Participate in the Employee Commute Options program to increase vehicle occupancy during peak hours.	?			
Recovered 108,204 tons of paper for recycling. At the going rate of $50/ton, disposing the paper in the landfill would have cost $5.4 million. The costs of collecting, shredding and baling the wastepaper were offset by the $3.4 million it brought in.	Historic			
Investigate ways to reduce temperatures of our ink-drying ovens.	?			
Investigate more energy-efficient computer terminals.	?			
Involve employees in energy reduction programs through updates via e-mail, employee newspaper, environmental publications, etc. Encourage suggestions concerning energy efficiency.	?			
Utilitze the latest, most energy-efficient technology in equipment expansions and retrofits.	?			

AP Actions

Office paper and cardboard recycling.	Completed		
Recycling of Nickel solutions instead of incineration.	Completed		
Plastic recycling (containers).	Completed		
New waste treatment chemistry yielding 60% less solids, double the metal content than before.	Completed		
Recycling of used flux and compressor oils by fuel-blending.	Completed		
Retrofit of ovens to natural gas.	New		
Retrofit of air compressors to natural gas.	New		
Using fresh air for compressors so that cooling would not be needed, also heating the building using air compressor waste heat.	New		
Multi-layer press retrofit from electric to natural gas.	New		
Energy efficient motors purchased over 5 hp.	New		
High efficiency lighting replacements.	New		
New energy efficient ventilation system.	New		
Recycling of router dust.	Completed		

AP Actions

Installation of total building automation (control/monitor with two remote stations at administrative residences).	New		
Replace select motors with high off and/or variable frequency drives.	New		
Night setback in unoccupied areas.	New		
Initiated computerized preventive maintenance program.	New		
Establish recordable PM program on filter replace, coil cleaning, damper maintenance.	New		
Regulate preventive maintenance on steam traps.	New		
Implemented full successive contracts with water treatment vendor.	New		
PSE & G std. offer program includes chiller plant expansion...	New		
Equipment performance curtailing for minimum occupied areas.	New		
Total housewide lighting retrofit.	New		
Corporate-wide trip reduction, car pooling. Participation rate is 10% due to the nature of the facility.	New		
Reclaim usable parts from old office equipment. Sell or give old furniture and office equipment to local charities.	Completed		
Perform own environmental impact assessments when evaluating product and facility decisions.	Completed		
Ensure that supplier or orginal equipment manufacturer has good environmental programs in place.	Completed		

AP Actions

Green Environmental Management: Committed to voluntary environmental measures that strive for continual improvements of environmental performance. Prefer methods which prevent pollution over other means of addressing pollution issues.	Completed		
Save documents electronically instead of on paper; proof documents on the screen before printing; use e-mail instead of paper-based mail.	Completed		
Establish a "double-sided" copying policy and ensure that copiers purchased have double-side capability. Make scratch pads from used paper.	Completed		
Automate office equipment to turn off during unoccupied periods or when not needed. When purchasing new equipment buy the higher efficiency models.	New		
Reuse packing materials and request the same from suppliers.	Completed		
Automate building to turn lights off when not needed and install occupancy sensors in areas of sporadic use.	New		
Automate building to reset thermostats during non-working hours and adjust set points w/comfort zones seasonally.	New		
Install window film on existing windows to decrease the shading coefficient and increase R-value.	New		
Install weather stripping, caulking, and seals on doors, windows and other openings; seal openings in walls for piping, electrical conduit, through-wall units, etc.	New		
Clean and/or replace filters regularly on heating and cooling systems.	New		
Participate in community activities which educate and promote energy conservation and pollution prevention.	Completed		
Ensure that supplies are shipped in packaging that is reusable, recyclable, and not excessive. Ensure that supplies meet environmental specifications. Purchase products with minimal packaging.	Completed		
Compost suitable food waste with landscaping wastes (done at home as well at the company).	Completed		
Refill/recycle toner cartridges from copiers/printers.	Completed		
Prevent overlapping operation of heating and cooling systems and reduce heating and cooling in little-used areas.	New		
Keep mailing lists current to avoid duplication.	Completed		
Inventory/Purchasing: Select products that promote waste reduction (our company offers only products which reduce energy consumption); purchase products made with recycled materials.	Completed		

AP Actions

Make greater use of natural lighting by installing window films to reduce glare. Increase the use of "tank lighting" such as desk and table lamps. Clean lamps, luminaries and interior surfaces of lighting fixtures on a regular basis.	New		
Use reusable dishes, utilities, mugs, etc. for employee breakroom.	Completed		
Insulate steam lines.	New		
Replace malfunctioning steam traps.	New		
Replace the condensate return tank.	New		
Replace existing T12 8' fluorescent lamps and standard ballasts with T8 8' lamps and electronic ballasts.	New		
Replacement of existing transfer dry cleaning machine with a new dry-to-dry machine which utilizes a fraction of the cleaning solvents.	New		
Steam heat recovery for FCC unit @ 11.7 mbtu/hr * 860 hrs. @ 76% efficiency.			
Heighten heat exchanger efficiency enhancements.			
Burner efficiency and control.			
Install variable speed drives on selected motors @ 9-1800 hp.			
Install high efficiency lighting systems @ 100 kW.			
Install high efficiency HVAC systems @ 60 tons.			
Reduce steam and compressed air losses in selected locations.			
Intsall high efficiency transformers and electrical distribution @ 9000 kva (est.).			
Install high efficiency 4160v motors @ 3-3200 hp (est.).			
Install high efficiency cooling towers @ 4-40 hp fans and 3-150 hp pumps.			
High efficiency, pre-heat exchanger/pinch technology for crude and FCC unit.			

AP Actions

Liquid waste generated by the filtration system will be concentrated in a multiple effect evaporator for disposal as cattle feed supplement.	New		
Began project that will treat 90,000 gallons per day of plant effluent utilitzing ultrafiltration, reverse osmosis, and evaporation. Clean water will be returned to the plant for olive processing.	New		
Adjust oil heat exchanger air-fuel ratios to maximize combustion efficiency. Payback of 0.2 years.	Expanded		
Repair compressed air leaks. Payback of 0.2 years.	Expanded		
Install methanation plant to dispose of solids removed from waste water. Payback of 4.4 years.	New		
Install outside air intake for air compressor. Payback of 0.2 years.	Expanded		
Replace paint lighting system with high efficiency lighting system and controls. Payback of 4.4 years.	New		
Install settling tank to pre-treat waste water prior to discharge to sewer. Payback of 1.6 years.	Completed		
Hook up HVAC system to EMS for better control of energy usage.	New		
Change from a solvent-based painting system to a water-based painting system.	New		
Economizer cycle added to HVAC system.	Accelerated		
Thermal storage project.	New		
Air handlers were optimized and the duty cycles were changed to work with the EMS.	Accelerated		
Office reduction of paper use. Increased use of e-mail and the addition of envelopes which can be sent many times through the office.	New		
Change out pumps and air handlers to variable speed drive systems.	Accelerated		
Energy Management System to control and track energy usage throughout the plant.	Accelerated		
Engineer out the use of Methyl Chloroform.	New		
Change out the old plant lighting with new, higher efficiency lighting	New		

AP Actions

Computers turned off when not in use.	Expanded		
Install an energy saver program on the desktop computers to reduce energy use while on.	Expanded		
Insulate and seal up the plant to reduce leakage.	Expanded		
Hook up all lighting and electrical processes to EMS for better control of energy usage.	New		
Add occupancy sensors to all of the rooms in the plant and offices.	Expanded		
Replace two old chillers with high efficiency chillers.	Expanded		
Started a carpool program.	New		
Connect pumps and air handlers to the EMS.	Accelerated		
All existing pumps were optimized to perform at peak efficiency.	New		
Implemented a recycling program to recycle wood, paper, and aluminum cans.	New		
Recycle iron and copper.	New		
Recycle oil and oil filters.	New		
Recycle antifreeze.	New		
Replace inefficient electric ovens with high efficiency gas ovens.	Expanded		
Improve energy efficiency in production and buildings.	?		
Conduct a company-wide evaluation of greenhouse gas emissions to identify emission reduction opportunities.	?		
Create a Climate Wise team comprised of energy, facilities, and environmental managers from each business unit.	?		
Trade or purchase old growth production lands for preservation.	?		
Create a system or program to protect old growth forests and other forest lands with higher sequestration rates in conjunction with local or national organizations such as the Conservation Foundation or in partnership with utilities.	?		
Support effective agroforestry programs in partnership with farm communities.	?		
Substitute waste forest products (biomass energy supplies) for fossil fuels.	?		
Re-vamp or phase-out antiquated combustion systems such as drying kilns and ovens.	?		
Improve energy efficiency in the pulp and paper milling process through straw pulping.	?		

AP Actions

Convert vehicle fleets to natural gas.	?		
Support employee carpooling programs.	?		
Sponsor community projects that promote and fund local tree planting and community light-colored surfacing efforts.	?		
Re-vamp or phase-out inefficient motors.			
Improve energy efficiency in the pulp and paper milling process through cogeneration.			
Improve energy efficiency in the pulp and paper milling process the reuse of heated waste water.			
Modernize forest management and harvest system practices and techniques.	?		

Q15.3 Please provide the level of funding for Climate Wise in FY 1997 and FY 1998, and the amount requested for FY 1999.

A15.3 FY1997 = $3,236,900
FY 1998 = $3,391,300
FY 1999 = not a line item

In the FY 1999 budget proposal, Climate Wise is one component of the "Industry Initiatives" line item (see response to Question 29).

Q15.4 Please identify all recipients of the funds--by fiscal year and by amount for each recipient--identified in the response to question 15.3 above.

A15.4 EPA interprets this question to be based on the misconception that EPA provides financial assistance to partners in this program. EPA does not provide any funding to program participants. Instead, EPA uses its funding to disseminate reliable financial and technical information to program partners to assist them in making better decisions for investing their own money. With improved information through voluntary partnerships, companies are able to make investments that simultaneously reduce greenhouse gas emissions and reduce energy bills.

Climate Change Technology Initiative Tax Credits

Q16. On page 8 of your written testimony, you state:

"The Initiative also includes $3.6 billion over five years in targeted tax cuts to help businesses and consumers buy and adopt these technologies.

- **Tax credits for highly fuel efficient vehicles: This credit would be $4,000 for each vehicle that gets three times the base fuel economy for its class beginning in 2003. A credit of $3,000 would be available beginning in 2000 for vehicles that get double the base fuel economy- for its class. These credits would be available to jump start these markets and would be phased out over time.**

- **Tax credits for energy efficient equipment: These credits (all of which are subject to caps) would include a 20% credit for purchasing certain types of highly efficient building equipment, a 15% credit for the purchase of rooftop solar systems, and a 10% credit for the purchase of highly efficient combined heat and power systems."**

Please specify--by year and by tax credit--the greenhouse gas reductions expected to be achieved through the application the Climate Change Technology Initiative tax credits proposed in the President's FY 1999 budget proposal.

A16. The President's Climate Change Technology Initiative is a comprehensive approach to reducing greenhouse gas emissions that includes not only tax cuts, but also spending to promote research and development of advanced technologies and to promote the use of today's efficient technologies. Because these strategies work together to help promote continued improvements in energy efficiency throughout the economy, the Administration has not attributed emissions reductions to specific tax proposals.

Industry Initiatives

Q17. On page 8 of your written testimony, you state:

"1. Industry Initiatives -- the President has invited entire industries to work with the Federal government and develop greenhouse gas plans. In addition to its partnerships with individual companies, EPA will consult with key industries to develop voluntary but aggressive strategies for further greenhouse gas reductions that improve overall productivity and promote the deployment of clean technologies such as the use of industrial combined heat and power, and to build a program that appropriately rewards early action. EPA will seek dialogue with key stakeholders throughout industry and the NGO community."

Q17.1 What is EPA's current (FY 1998) level of funding for such industry activities and what level is requested for FY 1999?

A17.1 FY 1998 Enacted = $20.9M
FY 1999 President's Budget = $51.6M

Q17.2 What does EPA have in mind about "a program that appropriately rewards early action"?

A17.2 EPA would like to ensure that there is an appropriate incentive structure for firms to reduce emissions in the period leading up to 2008.

Transportation Initiatives

Q18. On pages 8 and 9 of your written testimony, you state:

"2. Transportation Initiatives -- EPA will accelerate its efforts under the Partnership for a New Generation of Vehicles (PNGV), and will develop enabling technology for production prototypes for delivery and long-haul trucks that would achieve significant increases in fuel economy while meeting stringent emissions targets. The National Academy of Sciences has determined that EPA's renewable fuels application for 4SDI engines is the lead PNGV candidate technology. When complete, EPA's design will provide the basis for a viable and proven concept vehicle for commercialization. It will also provide a strong technical base from which to initiate additional EPA research into similar technologies for light truck application. EPA will also expand its work with state and local decision-makers to develop and implement transportation improvements that encourage "livable communities" -- compact, walkable and mixed use development -while reducing the growth in vehicle travel, emissions, and congestion."

Q18.1 Please provide the level of EPA funding for PNGV in FY 1997 and FY 1998, and the amount requested for FY 1999.

A18.1 FY1997 = $14,300,000
FY 1998 = $15,600,000
FY 1999 = not a line item

In the FY 1999 budget proposal, PNGV is one component of the "Transportation" line item (see response to Question 29).

Q18.2 Please provide the level of EPA funding requested for FY 1999 to "develop enabling technology for production prototypes for delivery and long-haul trucks that would achieve significant increases in fuel economy while meeting stringent emissions targets."

A18.2 See response to Question 29.

Q18.3 Please describe EPA's "work with state and local decision-makers to develop and implement transportation improvements that encourage 'livable communities' --compact, walkable and mixed use development -- while reducing the growth in vehicle travel, emissions, and congestion."

A18.3 EPA's work with State and Local decision-makers on the development of "livable communities" is undertaken primary through the voluntary program entitled "Transportation Partners." Transportation Partners was founded in 1995 as a cooperative program and has sought to reduce the growth of vehicle miles traveled (VMT) through the adoption of measures that provide or promote the use of non-single occupancy vehicle transportation choices for citizens. As part of the *Climate Change Action Plan*, Transportation Partners plays an important role in the nation's commitment to reduce U.S. greenhouse gas emissions to 1990 levels by the year 2000. Despite funding levels significantly below original projects, Transportation Partners has exceeded its target number of partners and is now serving over 300 partners nationwide.

Transportation Partners works with non-governmental organizations, or Principal Partners, to provide assistance to transportation projects across the country. The Principal Partners work directly with civic organizations, local and regional governments, transportation management associations and private businesses, referred to as project partners, to institute VMT-reducing transportation projects. Publications and technical assistance are provided to the project partners in three broad areas: *community design* or redevelopment strategies that facilitate walking, bicycling, and transit; *economic incentives* or market based measures such as parking cash-out programs or peak-travel pricing; and *technology* based projects such as telecommuting and automatic fare collection. Principal Partners have also hosted five major conferences this year with total attendance of over 1800 participants. This year, over 75 local workshops, on topics ranging from community walkability to calculating emissions from municipal fleets, and attracting more than 1000 participants, were held around the country.

Transportation Partners has been actively engaged in quantifying the carbon emissions benefits from these VMT reduction strategies. In 1996, Transportation Partners have reduced an estimated 76 million VMT or 0.11 MMTCe. Our data collection for 1997 is on-going, but initial estimates indicate that reductions for this year may be as high as 0.3 MMTCe.

Transportation Partners results in a number of additional benefits beyond greenhouse gas emission reductions. For example, air, water, and noise pollution are all reduced through the program's efforts. In addition, toxic chemicals, used motor oil, and vehicle parts disposal all result from automobile travel. By reducing VMT, Transportation Partners also is addressing these indirect impacts of vehicle travel.

Q18.4 Please provide the level of funding for EPA's "work with state and local decision-makers to develop and implement transportation improvements that encourage 'livable communities' -- compact, walkable and mixed use development -- while reducing the growth in vehicle travel, emissions, and congestion" in FY 1997 and FY 1998, and the amount requested for FY 1999.

A18.4 See response to Question 29.

Q18.5 Please identify all recipients of the funds--by fiscal year and by amount for each recipient--identified in the response to question 18.3 above.

A18.5 EPA interprets this question to be based on the misconception that EPA provides financial assistance to partners in this program. EPA does not provide any funding to program participants. Instead, EPA uses its funding to disseminate reliable financial and technical information to program partners to assist them in making better decisions for investing their own money. With improved information through voluntary partnerships, companies are able to make investments that simultaneously reduce greenhouse gas emissions and reduce energy bills.

<u>Buildings Initiatives</u>

Q19. On page 9 of your written testimony, you state:

> **"3. Buildings Initiatives. The buildings sector, which includes both homes and commercial buildings, offers a large potential for carbon reductions using technologies that are on the shelf today. However, consumers and businesses continue to invest substantial resources in equipment that is relatively energy inefficient, resulting in higher energy bills and higher pollution levels. One of the key challenges over the next decade will be to overcome market barriers, such as the lack of reliable information, and improve the markets for energy-efficient products. EPA will expand its partnerships with equipment manufacturers and building owners in order to provide reliable, easily understood information to a greater segment of the residential and commercial markets. EPA will also expand its work to support other Federal agencies in improving the energy performance of their facilities."**

Q19.1 What is EPA's current (FY 1998) level of funding for such buildings activities and what level is requested for FY 1999?

A19.1 FY1998 Enacted = $38,800,000
FY 1999 President's Budget = $78,100,000

Q19.2 Your description of EPA's "Buildings Initiatives" is very similar in many respects to activities supported by the Department of Energy. How do they overlap or duplicate each other, and how do they differ?

A19.2 There is no duplication between EPA's and DOE's buildings initiatives. Because a majority of U.S. greenhouse gas emissions are a result of energy consumption, and because the solution to climate change requires the more efficient use of our energy resources to deliver the services we need, it is most appropriate that the U.S. Department of Energy and the U.S. Environmental Protection Agency work together to improve the energy pathway of the United States. Under the Climate Change Technology Initiative's Buildings Sector programs, DOE and EPA have distinct but complimentary responsibilities that, in total, represent an integrated and coordinated Federal approach to providing the mid-term and long-term efficiency gains needed to help meet environmental and energy policy objectives. DOE's budget request outlines their major responsibilities. For example, DOE makes significant contributions in the Research, Development, and Deployment of advanced technologies that will provide continued opportunities for cost-effective investments that reduce energy use. DOE also issues energy efficiency standards that ensure a minimum efficiency level for many types of building equipment being sold today. Focusing on the significant opportunity for cost-effective pollution prevention without regulation, EPA joins DOE in working to form partnerships to deploy today's highly efficient energy technologies. There are some areas in particular where DOE and EPA have worked together -- for example, the Energy Star Label. The Energy Star label is the Federal government's symbol for energy efficiency, and it bears the names of both EPA and DOE. By working together, EPA and DOE have been able to provide a unified message to equipment manufacturers and consumers. EPA and DOE have formed hundreds of successful partnerships with equipment manufacturers, and the voluntary label can be found on thousands of different products. Because the Energy Star label bears both an environmental and an energy message, the DOE and EPA partnership is a sensible approach to program implementation. To avoid any duplication of effort, there is a Memorandum of Understanding between the two agencies that clearly designates the distinct responsibilities of each agency under the Energy Star labeling program.

<u>Carbon Removal</u>

Q20. On pages 9 and 10 of your written testimony, you state:

"4. Carbon Removal. EPA working with the U.S. Department of Agriculture will encourage the forest products sector to achieve greater reliance on biomass fuels as an energy source and be a supplier of carbon sequestration credits through afforestation and reforestation activities. EPA will accelerate efforts to promote the use of livestock based fertilizer products and more efficient use of nutrients from all sources."

Depending on the interpretations of Kyoto, we see tremendous opportunities to advance the objectives/goals of Kyoto using land management tools. Among these are forest management practices. Kyoto could create incentives to engage in afforestation activities, e.g. conversion of agricultural lands for conservation purposes or agroforestry. In addition, forest managers might engage in sustainable practices that increase carbon sequestration on existing forests. Kyoto also creates greater opportunities for the use of biomass as a "climate neutral" source of energy production.

Q20.1 Please describe EPA's "efforts to promote the use of livestock based fertilizer products and more efficient use of nutrients from all sources."

A20.1 In FY 1997 EPA convened a conference entitled "Strategies to Capitalize on the Animal Manure Resource" in cooperation with The Fertilizer Institute. The conference brought together many stakeholders including livestock producers and their national organizations, land grant university agricultural scientists, fertilizer dealers and manufacturers, federal and state agencies, agricultural equipment manufacturers, and agriculture organizations. Its goal was to start a national dialogue on the creation of market incentives that encourage the widespread and profitable use of animal manures in environmentally safe systems. One direct result of this conference was the FY 1997 funding of a pilot project in Texas in cooperation with USDA's Natural Resource Conservation Service to evaluate the feasibility of collecting, processing, and marketing dairy manure. In FY 1998, EPA, in coordination with USDA's Natural Resource Conservation Service, Cooperative State Research Extension and Education Service, and Agricultural Research Service, began an interagency agreement to develop threshold levels for phosphorus in soils throughout the United States. These levels will enable states to base livestock manure land application guidance or regulations on good science. In addition, many states fund nutrient management demonstration projects through EPA's Section 319 grant program (nonpoint sources). EPA will be working with the American Society of Agronomy to educate Certified

Crop Advisers on the environmental and agronomic benefits of proper application of livestock manure.

Q20.2 What is EPA's current (FY 1998) level of funding "efforts to promote the use of livestock based fertilizer products and more efficient use of nutrients from all sources" and what level is requested for FY 1999?

A20.2 FY 1998 = $120,000
FY 1999 = $1 million

The level of funding for the Section 319 projects by states either in FY 1998 or FY 1999 is unknown at this time.

Q20.3 Please identify all recipients of the funds--by fiscal year and by amount for each recipient--identified in the response to question 20.2 above.

A20.3 FY '98 -- Interagency Agreement with the Natural Resources Conservation Service. Funds will be transferred to land grant universities in the areas of concern: $120,000.

Recipients for the rest of FY '98 and FY'99 funds have not yet been identified.

<u>Crosscutting Analysis and Approaches</u>

Q21. On page 10 of your written testimony, you state:

"5. Crosscutting Analysis and Approaches. To build support for and the institutional capacity needed to implement a domestic and international carbon emissions trading program, EPA will work with developing nations and states and localities. Emissions from developing countries are growing rapidly and are projected to exceed those of developed countries within the next forty years. An effective, efficient global solution to climate change must be market-based and must involve both developed and developing countries. The Administration and EPA will work to secure additional international support for the American vision of global climate protection reflected in the Kyoto Protocol by assisting key developing countries in their efforts to reduce greenhouse gas emissions and address global climate change. EPA will also expand its work with states, which are key players, in efforts to reduce greenhouse gas emissions. EPA will provide support to states to help develop emission inventories and voluntary action plans, and implement and expand promising policy options identified by states in the greenhouse gas mitigation plans."

Q21.1 Please describe EPA's FY 1997 and FY 1998 "work with states, which are key players, in efforts to reduce greenhouse gas emissions" and "support to states to help develop emission inventories and voluntary action plans, and implement and expand promising policy options identified by states in the greenhouse gas mitigation plans."

A21.1 EPA's FY 1997 and FY 1998 voluntary State and Local program aims to build capacity at the state and local level making them full partners in the implementation of the Climate Change Action Plan, integrating climate efforts with complementary programs, and engaging public officials in climate policy-making. Through the State and Local climate change efforts, states and localities will (1) increase their understanding of the economic and environmental risks and impacts of climate change (for example, to public health); (2) assess and develop mitigation strategies that are cost-effective, environmentally sound and equitable; and (3) implement, evaluate and document results.

Q21.2 Please provide the level of funding for activities described in the response to question 21.1 in FY 1997 and FY 1998, and the amount requested for FY 1999.

A21.2 The FY 1997 operating plan allocated $3.3 million for State and Local activities. FY 1998 operating plan also allocates $2.8 million to support Climate Change Action Plan's State and Local activities. The FY1999 President's Request for the State and Local program is $5.0 million.

Q21.3 Please identify all recipients of the funds--by fiscal year and by amount for each recipient--identified in the response to question 21.2 above.

A21.3 EPA interprets this question to be based on the misconception that EPA provides financial assistance to partners in this program. EPA does not provide any funding to program participants. Instead, EPA uses its funding to disseminate reliable financial and technical information to program partners to assist them in making better decisions for investing their own money. With improved information through voluntary partnerships, companies are able to make investments that simultaneously reduce greenhouse gas emissions and reduce energy bills.

Q21.4 Please describe EPA's FY 1997 and FY 1998 and proposed FY 1999 "work to secure additional international support for the American vision of global climate protection reflected in the Kyoto Protocol by assisting key developing countries in their efforts to reduce greenhouse gas emissions and address global climate change."

A21.4 In FY1997 - FY1999, EPA provided support to the US Country Studies Program and the US Initiative on Joint Implementation (both interagency programs) to: 1) assist in the development of emissions inventories, mitigation and vulnerability assessments, and national action plans in developing countries; and 2) provide technical assistance to project developers and support for the proposal evaluation process for joint implementation projects that will build capacity, transfer technologies, and reduce greenhouse gas emissions in developing countries. Additionally, EPA conducted activities to elaborate on guidelines and methodologies for joint implementation efforts, reported to the UNFCCC on the USIJI program, and conducted policy-related research on cost-effective options to mitigate climate change impacts.

Q21.5 Please provide the level of funding for activities described in the response to question 21.4 in FY 1997 and FY 1998, and the amount requested for FY 1999.

A21.5 See response to Question 29.

Q21.6 Please identify all recipients of the funds--by fiscal year and by amount for each recipient-identified in the response to question 21.6 above.

A21.6 To support the activities described in 21.4 in FY 1997-99, recipients of the funds included various consulting and contracting firms, non-governmental organizations, government laboratories, program partners, and other entities.

The Lancet **Study on Particulate Matter-Related Health Impacts of Greenhouse Gas Mitigation and Reduction in Deaths and Greenhouse Gas Emissions Due to EPA's Recently Promulgated Fine Particulate Standard**

Q22. On page 11 of your written testimony, you state:

"The Lancet, a highly respected British medical journal, recently published a peer-reviewed study of the particulate matter-related health impacts of fairly aggressive, worldwide greenhouse gas mitigation. The analysis found that an estimated 8 million deaths globally due to exposure to fine particles could be avoided between 2000 and 2020 if substantial steps were taken to limit greenhouse gas emissions from burning fossil fuels. In the United States alone, the study reports that thousands of deaths annually could be avoided during the 2000-2020 period. EPA's recently promulgated fine particulate standard begins to address this public health concern and should result in both some reductions in greenhouse gas emissions along with reducing the number of deaths associated with exposure to fine particles."

Q22.1 Please provide a copy of The Lancet article referred to above.

A22.1 See attached.

Articles

Short-term improvements in public health from global-climate policies on fossil-fuel combustion: an interim report

*Working Group on Public Health and Fossil-Fuel Combustion**

Summary

Background Most public-health assessments of climate-control policies have focused on long-term impacts of global change. Our interdisciplinary working group assesses likely short-term impacts on public health.

Methods We combined models of energy consumption, carbon emissions, and associated atmospheric particulate-matter (PM) concentration under two different forecasts: business-as-usual (BAU); and a hypothetical climate-policy scenario, where developed and developing countries undertake significant reductions in carbon emissions.

Findings We predict that by 2020, 700 000 avoidable deaths (90% CI 385 000–1 034 000) will occur annually as a result of additional PM exposure under the BAU forecasts when compared with the climate-policy scenario. From 2000 to 2020, the cumulative impact on public health related to the difference in PM exposure could total 8 million deaths globally (90% CI 4·4–11·9 million). In the USA alone, the avoidable number of annual deaths from PM exposure in 2020 (without climate-change-control policy) would equal in magnitude deaths associated with human immunodeficiency diseases or all liver diseases in 1995.

Interpretation The mortality estimates are indicative of the magnitude of the likely health benefits of the climate-policy scenario examined and are not precise predictions of avoidable deaths. While characterised by considerable uncertainty, the short-term public-health impacts of reduced PM exposures associated with greenhouse-gas reductions are likely to be substantial even under the most conservative set of assumptions.

Lancet 1997; **350:** 1341–49

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Introduction

Since the industrial revolution, the contribution of anthropogenic sources of greenhouse gases to the global environment has increased significantly.[1] Atmospheric concentrations of greenhouse gases, including carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), are of greater importance today than at any other time in human history. These trends can be largely attributed to human activities, primarily fossil-fuel combustion, and change in land use and agricultural practices. In the absence of efforts to reduce greenhouse gases, the concentrations of these gases are expected to grow significantly throughout the next century. The mid-range estimate from the Intergovernmental Panel on Climate Change (IPCC) is that human-induced climate-change will increase surface temperatures by about 2°C by the year 2100;[2] many uncertainties exist about this projection.

In an effort to protect the global-climate system for future generations, over 150 nations signed the UN Framework Convention on Climate Change (UNFCCC) in June, 1992.[3] The UNFCCC established the objective of stabilising atmospheric greenhouse-gas concentrations at levels that would avoid dangerous anthropogenic interference with the global-climate system. Signatory countries will be considering options to control greenhouse gases at the third conference of parties in Kyoto, Japan, in December, 1997.

Short-term public-health impacts have generally not been considered in assessments of global-climate change. Two studies,[4,5] for example, have projected that well into the next century, weather patterns resulting from climate change are expected to affect the health of future generations. Heat-related mortalities and illnesses, physical and psychological traumas, and changes in vector-borne and infectious diseases, food supplies, and coastal sea-levels are expected to become evident. With various models, we estimate likely public-health benefits of current and future global-climate-change mitigation policies in the first two decades of the 21st century in developed and developing countries.

Many of the fossil-fuel combustion processes that produce CO_2 and other greenhouse gases also produce a host of air pollutants such as particulate matter (PM), sulphate, ozone, and other pollutants, all of which have short-term adverse effects on public health. We use PM as a sentinel air pollutant because it is commonly associated with fossil-fuel combustion. Extensive public-health literature in several countries has shown that both mortality and morbidity are significantly associated with exposure to PM.[6,7] Most air pollutants from fossil fuels have local impacts but some airborne pollutants (eg, fine particulates) can be transported thousands of miles and have global impacts.[8]

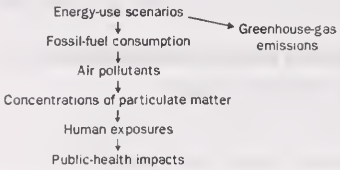

Figure 1: **Models used in estimating the global impact of fossil-fuel consumption on public health**

We combined analyses from several independent models of energy consumption (to provide a first approximation of likely CO_2 emissions), associated concentrations of PM, and probable increases in mortality associated solely with PM by the year 2020 (figure 1). This analysis presents a scenario-based order-of-magnitude estimate of the possible size of the air-pollution impacts on populations in developed and developing countries.

Methods

Scenario development

Estimation of the consequences for public health of projected global events requires the development of scenario-based impact assessment that relies on complex models of environmental change.[9] Our study develops two possible CO_2 emission scenarios: a business-as-usual (BAU) scenario which updates IPCC's 1992 analysis of expected trends in energy consumption and associated CO_2 emissions;[10] and a hypothetical climate-policy scenario, which considers the stated intentions of the European Union regarding proposed reductions in CO_2 emissions for developed countries,[11] coupled with additional measures by developing countries. Under our hypothesised climate-policy scenario, developed countries would undertake concerted and binding efforts to reduce energy-related CO_2 emissions 15% below 1990 levels by the year 2010. Under this same climate-policy scenario, developing countries are assumed to reduce their emissions 10% below their levels of greenhouse-gas emissions forecast for 2010—that is, 10% below what would otherwise be their BAU trends by 2010. This is consistent with agreements made by developing countries under the Berlin Mandate to advance implementation of existing commitments to promote technologies, practices, and processes that reduce greenhouse-gas emissions.

Both these scenarios assume that total energy use and efficiencies in the developing countries continue to increase to meet the needs of economic growth. The differences between them lie in the rates of growth in energy use, the fuel mixes, and their combustion and end-use efficiencies. Under each of these scenarios, emissions of PM are taken as representative of general ambient air pollution associated with fossil-fuel combustion and CO_2 emissions. Based on projected concentrations of PM, we estimate annual and cumulative numbers of avoidable deaths in the years 2010 and 2020 among adults aged over 30 years and infants of up to 1 year in developed (annex 1) and developing (non-annex 1) countries (UNFCCC nomenclature). Avoidable deaths refers to the estimated annual premature mortality associated with PM from modelled fossil-fuel combustion (ie, attributable risk) that could be avoided by adopting the hypothesised climate-policy scenario. Because the aerodynamic size of the particles produced is of great importance, our model estimates the emissions and concentrations of particles that are less than 10 μm (PM_{10}) and fine particles of less than 2·5 μm ($PM_{2.5}$). A host of other adverse acute and chronic health effects are also associated with PM and other air pollutants, but are not analysed here.[12,13]

Fossil-fuel consumption and carbon emissions

Future fossil-fuel consumption and resulting emissions of greenhouse gases and other air pollutants reflect complex interactions of several key variables, including economic activity, transportation modes, demographic trends, the rate and nature of technological innovations, and energy prices. The IPCC devised six well-documented projections of greenhouse-gas emissions in 1992.[14] The IPCC used the Atmospheric Stabilisation Framework (ASF) model to relate socioeconomic scenarios to carbon emission trajectories. The ASF model contains detailed representations of fossil-fuel consumption for four sectors (electric utility, residential/commercial, industrial, and transportation) for nine global regions.

All CO_2 emission estimates in this paper refer to emissions attributable to the combustion of fossil fuels, which represent about 75% of current global anthropogenic emissions of CO_2.[15] The CO_2 emission projections presented in this paper fall within the range of other emission projections documented in the literature. The 8·3 billion metric tonnes of carbon (BMTC) from fossil-fuel combustion presented in this paper for 2010 is slightly lower than the estimate of 8·8 BMTC as predicted by Energy Information Administration.[16] Our 2020 projection of 10·7 BMTC is higher than the IIASA/WEC projection of 8·4 BMTC[17] and similar to the Shell Oil sustained-growth scenario estimate of 10·5 BMTC.[18]

The input in this study has been updated to reflect more recent population projections, the breakup of former Soviet Union, and lower anticipated fossil-fuel prices. The model assesses CO_2 emission-reduction goals, by choosing the most efficient and least cost emission-reduction opportunities available in each region, and recognises efficiency improvements in many developing countries.[19] The global-population data used for these scenarios are consistent with the World Bank's medium-growth assumptions.[20] The gross national product (GNP) growth assumed for the BAU scenario is slightly higher than the one used in the IS92a scenario, which reflects several economic, energy, and climate-change-related studies.[21,22]

Table 1 and figure 2 indicate several trends and associations of fossil-fuel consumption patterns modelled under both the BAU and climate-policy scenarios. In 1990, despite having only 24% of the world's population, annex 1 countries accounted for 70% of global fossil-energy consumption and 68% of carbon emissions from fossil fuels. Under BAU, overall growth in CO_2 emissions from annex 1 countries is relatively moderate through the projection period, 1990–2020, rising by only 17·5% through 2020. This moderate growth may be explained by current trends of fossil-fuel consumption patterns in Russia and the former Soviet Union. These regions

	Year									
	1990		2010				2020			
	A1	NA1	BAU A1	BAU NA1	CP A1	CP NA1	BAU A1	BAU NA1	CP A1	CP NA1
Fossil fuel										
Coal	58	38	50	75	31	62	44	100	31	76
Oil	92	41	110	99	94	97	118	152	95	150
Natural gas	59	12	66	35	64	35	77	64	71	64
Total fossil-fuel use	209	91	226	209	189	194	239	316	197	290
Carbon emission										
Billion metric tonnes (BMTC)	4	1·9	4·2	4·1	3·4	3·7	4·7	6	3·4	5·4
Relative carbon emissions	68%	32%	51%	49%	48%	52%	44%	56%	39%	61%

A1=developed (annex 1) countries; NA1=developing (non-annex 1) countries; BAU=business-as-usual scenario; CP=climate-policy scenario.

Table 1: **Fossil-fuel energy use (10^{18}J) under business-as-usual and climate-policy scenarios**

markedly differ from other annex 1 countries, in that sharp declines in energy consumption are not assumed to reach 1990 levels again before 2020. As a consequence, future increases in emissions in annex 1 countries under the BAU scenario are masked by these reduced consumption patterns in Russia and the countries of the former Soviet Union.

The expected growth in energy-related CO_2 emissions of non-annex 1 countries under BAU by 2020 exceeds the total level of emissions of annex 1 countries in 1990. Non-annex 1 countries' carbon emissions resulting from consumprion of fossil fuels are expected to rise from 1·9 BMTC in 1990 to 4·1 BMTC in 2010, a 116% increase over 30 years. In 1990, annex 1 countries produced 68% and non-annex 1 countries produced only 32% of total global carbon emissions. Under the BAU scenario, by the years 2010 and 2020, non-annex 1 region's projected contributions will be 4·1 and 6 BMTC, respectively. On the other hand, if the climate-policy scenario is implemented, by the years 2010 and 2020, non-annex 1 region's projected carbon emissions could be reduced to 3·7 and 5·4 BMTC, respectively. Figure 2 shows the relative contributions of developed and developing countries to fossil-fuel use for the years 1990, 2010, and 2020 under both scenarios. The global fossil-fuel consumption is expected to be less under the climate policy scenario, which reflects increased fuel-combustion efficiencies, conservation measures, and improved technologies. We assume that there is no cross-border trading of greenhouse gases. Under the climate-policy scenario, CO_2 emissions decrease more than fossil-fuel consumption as countries switch away from coal to less polluting fuels, such as natural gas.

Pollutant emissions and concentrations

The following discussion outlines the modelling protocol followed in this study along with a brief description of key assumptions and sensitivity analyses.

A PM source-receptor matrix[23] was used to derive concentration patterns for PM_{10} and $PM_{2.5}$ per unit of energy use for each of the four sectors and three fossil-fuel types (coal, oil, and natural gas). The source-receptor coefficients were calculated with large-scale air-dispersion models that were based on emission inventories calibrated with and matched to extensive monitoring data in USA for 1990–1994.[24] In addition to calculation of concentrations of primary particles (those emitted directly by sources), the model also incorporates the secondary conversion of gaseous precursors (SO_2 and NO_x) to fine particulates as they are transported through the lower atmosphere. The source-receptor-matrix model yields smoothed, area-wide averages of PM_{10} and $PM_{2.5}$ concentrations for each IPCC region and does not estimare local airborne-pollutant levels at specific receptor sites; the latter air-pollutant estimates are generally calculated with Gaussian air-dispersion models that incorporate only local emission inventories and meteorological data. To do this analysis, we assume that airborne fine particles travel hundreds of miles through the atmosphere and their estimated regional concentrations are not very sensitive to the details of the modelling matrix. This contrasts with the well-known difficulty of modelling for short-term ozone episodes over a small geographic area. Evidence supporting the long-range transport of fine particles can also be found—eg, in

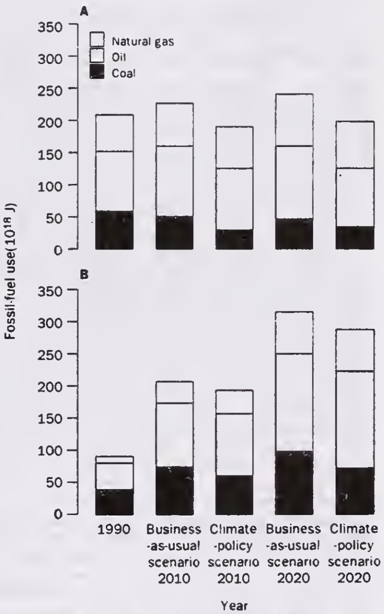

Figure 2: **Fossil-fuel use under business-as-usual and climate-policy scenarios in developed (annex 1; A) and developing (non-annex 1; B) countries**

the report of the second World Meteorological Organization meeting of experts to assess the response to and atmospheric effects of the Kuwait oil fires.[25]

Applying such a large-scale air-dispersion model carries with it several assumptions that could result in a misestimation of actual PM concentrations. In the absence of data on typical chimney heights in other parts of the world, for example, we have assumed that the distribution of chimney heights in the USA is representative of that found elsewhere. Should average heights of chimneys in a given region be lower than in the USA, the likely consequence would be higher local concentrations of particles and their precursors, and lower concentrations at greater distances downwind. Conversely, higher chimneys could yield lower concentrations near a given source but higher concentrations further downwind. A second key assumption is that the spatial association between emission sources and population densities in the USA is representative of the rest of the world. In some developing regions, such as the mega-cities of Southeast Asia, whose population patterns are more geographically dense, this approach is likely to underestimate actual human exposures to airborne pollutants. Also, the source-receptor-matrix model makes no estimates of indoor air-pollutant exposures to PM from coal or biomass used for cooking and heating. Such exposures are known to be very high in several developing regions, such as China, Africa, and India.[26]

Our modelling indicates that concentrations of PM from a fixed quantity of emissions in hot and dry regions are about one-third of what would be expected from those same emissions under most other climatic conditions. The likely reasons for this are: higher ambient temperatures coincide with greater mixing heights, hence a greater volume of air for dispersion; and the conversion of gaseous PM precursors such as SO_2 into intermediate products (sulphuric acid) requires the presence of water vapour. Where less water vapour is available, conversion rates are slower and conversion takes place over longer distances. Therefore, regional levels of PM are expected to be lower in dryer climates.

To capture these influences of climate on PM concentrations, the USA was divided into four roughly equal geographic zones based on long-term climatic data: hot/dry, hot/wet, cold/dry, and cold/wet. Unique source strengths for each sector/fuel were derived for each zone. Similar climatic data for each of the remaining eight global regions were used along with data on population densities to obtain the appropriate, representative weighting among USA climate zones—eg, 90% of the population of the Southeast Asia group was found to reside in a climate which most closely resembles the hot/wet designation, while 10% resides in a hot/dry grouping; none was in the cold/dry or cold/wet zones. To derive an overall Southeast Asia estimate, the source-receptor association for the hot/wet USA zone was weighted 90%, and the hot/dry zone 10%. Had we not adjusted the source-receptor matrix to account for regional differences for climate, and instead used the USA climate as a proxy for the rest of the world, then the modelled concentrations of PM would have been from 16% (climate policy Asia) to 130% (climate policy Europe) lower.

This analysis projected future global patterns of energy consumption and adjusted the overall USA source-receptor association to account for climate differences in other global regions. To project likely changes in concentrations of PM, it is also necessary to estimate future efficiencies of pollution-control equipment and policies unrelated to climate-control mitigation. In our analysis, two alternative pollution-control strategies were assumed to occur, in developed and developing regions. The USA Organisation for Economic Co-operation and Development (OECD)-West and OECD-Asian countries were assumed to use USA controls, including SO_2 and NO_x controls outlined in the USA, 1990, Clean Air Act. These do not reflect controls that individual states of the USA might adopt as a result of recent revisions to ozone and PM National Ambient Air Quality Standards, which are not expected to go into effect until after the adoption of climate-change mitigation strategies. All other regions were assumed to start with no controls in the year 2000. By the year 2020, these other regions were assumed to attain 1990 USA control levels for transportation-related emissions and 1970 USA control levels for point-source emissions.

Our results are sensitive to the estimation of pollution-control efficiencies for fuel combustion because emission rates change in relation to these values. This is especially true for situations where high levels of control are estimated, because the difference between 90% and 99% control is a ten-fold difference in emissions. For countries that may have more stringent control programmes than the USA (eg, certain sectors in Japan), use of USA standards as a proxy may overestimate future PM concentrations. It is also possible that our assumptions about future pollution-control efficiencies are too optimistic for developing countries; if so, then we will have underestimated emissions and associated health effects of the control scenarios. The sensitivity of the analysis to assumed control levels was evaluated by calculating PM concentrations in non-annex 1 regions and Eastern Europe and former Soviet Union, which would result in the absence of controls. Analysis for 2020 showed that removing controls would yield PM_{10} and $PM_{2.5}$ concentrations of 65% and 32% higher, respectively, than the values calculated in the BAU analysis.

Further refinements to transportation-related emissions in all non-USA regions were made to account for the much higher reliance on diesel fuel in most of the world than in the USA.[27,28] The fraction of the energy consumed in the transportation sector which is diesel fuel is different in each country (eg, 60% in Latin America, 20% in the USA) and the fraction is assumed to remain constant throughout the study period. These refinements also assume a steady reduction in use of lead in petrol starting from present levels in the year 2000 to zero in 2010. Increased use of catalytic converters to control vehicle-exhaust pollutants will accompany phase-out of lead.

In the USA, data indicate that ambient PM_{10} concentrations are on average 65% of total suspended particulate concentrations; $PM_{2.5}$ concentrations are on an average about 50% of PM_{10} concentrations; and fossil-fuel combustion accounts for about 45% of measured $PM_{2.5}$ concentrations.[23,24] To validate modelled PM concentrations, ambient monitoring data were gathered for about 40 countries. Virtually all of the data, however, were for total suspended particulate and no data were found which established the fractional contribution from fossil-fuel combustion. If one were to assume that the percentage of total suspended particulate that is contributed by fuel-combustion sources in the USA holds throughout the world, then estimated PM concentrations should be two to ten times higher than those developed in this study. In our judgment, it is highly unlikely that other regions experience long-term average PM concentrations from fossil-fuel combustion that approach such levels. Total suspended particulate concentrations in most of the world are at least twice as high as those in the USA; this is likely due to factors such as much higher contribution to the coarser fraction (>2·5 μm) from such sources as wind-blown dust (eg, Middle East) as well as a higher fine fraction (<2·5 μm) contribution from sources such as biomass burning from heating, cooking, and forest clearing (eg, Southeast Asia).

Health-impact estimates

Extensive public-health literature in several countries shows that both mortality and morbidity are significantly associated with exposure to PM.[6,7] Besides mortality, studies in several countries have associated PM with cardiovascular and respiratory morbidity (eg, increased hospital admissions and emergency-room visits for acute and chronic pulmonary effects, including bronchitis, asthma, cough and wheeze).[6,7,29] Little is known about the mechanism of action of PM. Some toxicological studies have produced bronchitic responses,[30] arrhythmias,[31] and exacerbation of pneumonia in rats[32] from exposure to fine particles, which are similar to those observed in epidemiological studies. It has been found that tiny respirable particles or airborne aerosols can interfere directly with pulmonary function and plasma viscosity in animals and human beings.[33-35] Mortality effects have consistently been associated with short-term and long-term exposure to PM in more than 40 studies done in over ten countries.[6,7,36-38]

The short-term exposure studies use daily time-series analysis to assess changes in mortality in the general population that are associated with changes in daily concentrations of PM. Long-term exposure studies of PM have used a prospective cohort design, which allows the adjustment of potential confounders in the assessment of the association between PM and mortality.

Health benefits from reductions in PM have been derived previously from epidemiological studies done in the USA and in Europe.[29,38,39] Long-term exposure studies were used as the basis for the quantitative analysis because the results from these analyses have followed single cohorts and adjusted for important confounders. These analyses suggested mortality effects from both long-term and short-term exposure to PM.[6,7,41] Epidemiological studies were chosen for this quantitative analysis only if they reported the relative risk (RR) as a monotonic function of PM concentrations. The two age groups for which RR has been estimated in long-term studies are adults aged over 30 years and infants aged between 1 month and 1 year. To evaluate the impact of PM concentrations on adult mortality, the paper by Pope and colleagues was selected as the basis for quantitative analysis.[42] For infant mortality, we used a study by Woodruff and colleagues[43] that reported RR as a continuous monotonic function of PM concentrations. Pope and colleagues found that a 24·5 μg/m³ increase in $PM_{2.5}$ is associated with a 1·17 (95% CI 1·09–1·26) increase in RR of total mortality for adults over 30 years. Woodruff and colleagues, found that for a 10 μg/m³ increase in PM_{10}, an odds ratio of 1·04 (95% CI 1·02–1·07) for increases in total infant mortality between 1 month and 1 year associated with increases in PM_{10} concentrations.

We assume that the association is the same in the rest of the world as it is in the USA. Epidemiological studies have found a relatively consistent association between short-term exposures to PM and mortality in many countries, including Chile, Brazil, and Western Europe.[6,37] Given the relatively consistent association found between short-term exposure to PM and mortality across countries, it is reasonable to assume that the health effects from long-term exposures to PM in other regions of the world parallel those of the USA.[6]

The association between change in $PM_{2.5}$ and PM_{10} and change in mortality risk is modelled as an exponential function. The exponential functional form for the RR comes from the specification of the logistic regression model used in the study by Woodruff and colleagues, and the Cox's proportional hazard model used in the Pope study for evaluation of the association between PM and mortality. In this model, the RR associated with a PM change of Δ PM is:

$RR\ (PM) = \exp\ (\beta\ \Delta\ PM)$

The slope coefficient, β, is derived from the chronic-exposure epidemiological studies selected for use in this analysis, and Δ PM is the incremental change in the annual mean (or median) PM concentration, had a policy-based scenario not been adopted. The risk reduction associated with adoption of the policy is:

$[\exp\ (\beta\ \Delta\ PM)-1]$.

The estimated regional incidence of avoided premature morality is:

Δ mortality=(RR [Δ PM]-1) (mortality rate) (population), where the mortality rate and population are the adult or post-neonatal regional estimates, derived from projections of population by age and infant mortality rates by country. These were obtained from the Bureau of Census (USA) international database and aggregated to a regional level. The projected baseline age-adjusted regional adult (>30 years) mortality rates were calculated from individual country population projections (by 5-year age group), adjusted for immigration and emigration with World-Bank projected net-migration rates.

The source-receptor-matrix estimates annual mean PM concentrations. The RRs in the Pope study are based on the annual median of daily PM concentrations, which is usually lower than the mean for air-pollution concentrations.[42] PM data, from the USA, suggests that a γ distribution best describes the observed skewed distribution of daily PM levels.[39] Assuming a γ distribution, an estimated median can be derived from the mean and an estimated maximum daily level. Observed population-weighted peak-to-mean ratios from four USA geographic zones are applied to the source-receptor association. A maximum likelihood routine was used for each region in the climate-policy scenario to estimate the γ distribution with the estimated mean and maximum daily level.

Results

The scenarios that form the basis for this exercise rest on complex models of energy-use trends, estimated emissions of carbon, projected levels of PM, and associated impacts on mortality. Each of these models

Year	Annex 1	Non-annex 1	Total
2000	0	0	0
2005	56 000 (31 000–83 000)	137 000 (75 000–204 000)	193 000 (106 000–287 000)
2010	89 000 (49 000–131 000)	286 000 (157 000–425 000)	375 000 (206 000–557 000)
2015	106 000 (58 000–156 000)	508 000 (278 000–750 000)	614 000 (337 000–906 000)
2020	138 000 (76 000–203 000)	563 000 (309 000–831 000)	701 000 (385 000–1 034 000)
Total cumulative* avoided mortality 2000–2020	1 670 000 (900 000–2 500 000)	6 340 000 (3 500 000–9 400 000)	8 010 000 (4 400 000–11 900 000)

*Cumulative is sum of annual deaths each year between 2000 and 2020. A1=annex 1 (developed) countries; NA1=non-annex 1 (developing) countries.

Table 2: **Annual avoided mortality with 90% CIs (combined adult and neonatal infants) from climate-policy scenarios (15% below 1990 levels by 2010 for A1 countries and 10% below BAU levels by 2010 for NA1 countries)**

necessarily has several assumptions and includes many uncertainties. Of the many limitations of this exercise, two stand out: we have only calculated mortality impacts of PM for adults over age 30 and infants of age 1 month to 1 year; and we do not provide estimates of morbidities related to air pollutants from fossil-fuel combustion. The quantitative estimates of public-health impacts generated through this assessment should be understood as a first approximation of the likely magnitude of the effect, and not as representing precise predictions of avoided mortalities.

With these caveats in mind, if the climate-policy scenario were to be implemenred, substantial improvements in fuel efficiency would be realised by 2020, and major reductions in PM pollution would be achieved. By the end of the second decade of the next century, the policy we have outlined here would avoid about 700 000 deaths annually (90% CI 385 000–1 034 000), of which 563 000 (309 000–831 000) and 138 000 (76 000–203 000) would occur in non-annex 1 (developing) and annex 1 (developed) countries, respectively (table 2). Note that the CI only reflects uncertainties in the epidemiological studies. If BAU climate policies continue, the greatest impacts will occur in developing countries.

We estimate that implementation of the climate-policy scenario could prevent up to 8 million deaths (90% CI 4·4–11·9 million) worldwide during the first 20 years of the next century, corresponding to 1·67 million (0·9–2·5 million) and 6·34 million (3·5–9·4 million) avoided deaths in developed and developing countries, respectively. There are higher expected deaths in developing countries compared with developed countries because of the higher proportional expected changes in PM concentrations under the climate-policy scenario.

To assess the sensitivity of the numbers to certain key assumptions in the estimation of PM concentrations, we considered two analyses. The first assesses the effect of assuming that the USA climate is representative of that in each of the other global regions examined. The second assesses the effects of assuming that there is no change in emission-control levels in the BAU baseline for the non-annex 1 countries and in Eastern Europe and the former Soviet Union. Table 3 presents the results for the cumulative number of deaths avoided under each of these scenarios. If we assume that the climate in the USA is the same in the rest of the world, this results in fewer estimated avoidable deaths than our primary health analysis between 2000 and 2020 in both non-annex 1 countries (3·8 million *vs* 6·3 million in our primary analysis) and annex 1 countries (1·2 million *vs* 1·7 million). The alternative assumption, about control levels in the BAU baseline, results in more estimated avoidable deaths in non-annex 1 countries (7·6 million *vs* 6·3 million).

Changes in model assumptions	NA1 countries	A1 countries	Total
Primary health analysis	6 300 000	1 700 000	8 000 000
Holding worldwide climate estimate same as in the USA	3 800 000	1 200 000	5 000 000
Holding emission control levels constant in the 8AU in NA 1 and Eastem Europe	7 600 000	1 700 000	9 300 000

NA 1=developing (non-annex 1) countries. A1=developed (annex 1) countries; 8AU=business-as-usual scenario.

Table 3 : **Sensitivity analysis of avoidable deaths from climate policy: 2000 to 2020**

Discussion

One of the most critical set of assumptions in this scenario assessment is that present levels of PM are causing adverse effects on mortality of the magnitude reported by Pope and colleagues. The assumption that fine particles are the direct cause of these effects, and not merely correlated with them is also critical to our analysis. It is these fine particles that can be transported globally because they are not trapped by conventional particulate-control technologies, are buoyant, and can travel thousands of miles through the air before they are deposited. Fine PM can produce effects on health in distant countries.

The climate-policy scenario that we use makes several assumptions that affect the estimates of the public-health impact of improved policies for climate control. We assume an ambitious phase-in of pollution-control equipment in developing countries from policies unrelated to the climate-change-mitigation scenarios. If countries fail to use such pollution-control equipment, air-pollutant emissions will increase, and associated deaths and illnesses will be higher than those estimated under the BAU scenario, as seen in the sensitivity analysis. The effectiveness of policies to reduce greenhouse gas in the climate-policy scenario would be even greater. Second, the air-quality modelling protocol we use assumes that the USA distribution of chimney heights is representative of that throughout the world. Many developing countries have lower chimneys for power plants and industrial boilers and greater population densities surrounding industrial facilities, so this assumption probably causes an underestimation of avoided deaths from greenhouse-gas reduction in the non-annex 1 countries. However, if populations are concentrated at greater distance downwind, then lower chimney heights would probably yield lower PM exposures and result in an overestimation of avoided deaths. Third, the analysis does not include reductions in morbidity due to lower PM, or reductions in morbidity from other pollutants.

There are several uncertainties associated with the use of the prospective cohort studies for estimation of mortality effects from PM exposure worldwide. While the prospective cohort studies have attempted to account for all important confounders, some potential confounders may not have been considered. However, sensitivity analyses done in the study by Pope and colleagues found that the association between PM and mortality was relatively insensitive to several important potential confounders, including occupational exposure and smoking. This analysis also assumes there is a consistently increasing association between long-term exposure to PM and increased mortality risks, which is the same in the rest of the world as it is in the USA. In most developing countries, exposure to PM is an order of magnitude or more higher than that in the USA. Additional increases in mortality risks could diminish as exposures approach a saturation level. If the exposure response is not the same at these higher doses, then extrapolation of the USA estimates to developing countries may overestimate the avoided deaths in non-annex 1 countries. The results from the Pope study, of adult mortality, probably reflect both the effects of long-term and short-term exposure to PM, and there is possibly some overestimation of the annual avoided mortality associated with estimated annual decrements in PM. Another factor that could lead to overestimation is that PM levels in the USA have generally improved over the past few decades, especially for coarse particulate levels. If the premature mortality effects are related to cumulative exposure over a long period, then the observed effects in the Pope study could be associated with a larger PM change than observed (leading to a smaller risk per unit change).

Our analysis accounts for the age-distribution of the populations affected. If the RR is higher for older people, then the analysis could overestimate mortality effects in non-annex 1 countries. However, the younger populations of developing countries must often confront other health threatening conditions (eg, malnutrition), which may increase their vulnerability to pollutants. Estimates of the percentage of cardiorespiratory deaths in non-annex 1 countries (except for subSaharan Africa) is similar to that in annex 1 countries, indicating that it is reasonable to apply PM associations found in the USA to other countries. While we are not aware of any attempt to replicate the study by Woodruff and colleagues, similar results of infant mortality associated with PM have been found in the Czech Republic.[40]

The quantification of mortality benefits derived from our analysis only considers outdoor sources of PM from fossil-fuel combustion. For many countries around the world, burning biomass indoors can also be an important source of PM. For example, in China, households burn about 500 million tons of biomass fuels for cooking and heating each year.[44] The suspended PM in Chinese households often exceeds recommended air-quality guidelines by WHO by more than tenfold.[45] For most of the Chinese population, the health impacts from indoor exposure to air pollutants greatly exceed that of workplace or outdoor exposure. Data from a series of studies and official disease statistics suggest that air pollution from both indoors and outdoors is responsible for more than 1 million deaths per year in China, or about one in every eight deaths nationwide.[46]

In 1990, lower-respiratory-infections were the leading components of disability adjusted life years.[47] By 2020, respiratory-related diseases are projected to rank among the top ten causes of poor health in the world. The total number of annual deaths that could be avoided under the climate-policy scenario in 2020 in much of the developed world almost equals the projected number of fatal injuries caused by automobile accidents.[48] In the USA, by the year 2020, at least 33 000 deaths a year could be avoided from implementation of the climate-policy scenario. This projected number of avoidable deaths in the USA is of the same order of magnitude as currently occurs as a result of several major causes of death from illnesses, each of which is subject to major public-policy interventions, including human immunodeficiency and chronic liver diseases.

Newspaper reports this year from Sumatra, Borneo, and other regions[49] indicate that measured levels of air pollution associated both with burning forests and air pollution from energy production sometimes exceed the levels measured in London during the killer fog of 1952. This episode of elevated pollution in London was associated with nearly 3000 excess deaths in 1 week.[50]

Health patterns in any region reflect an intricate combination of factors: poverty, nutrition, population density, housing and sanitation, smoking, and workplace and environmental factors. While environmental factors cannot account for all these patterns, they are important because they can be changed by public policy. Patterns of rapid growth and development in emerging mega-cities of the developing world can impose significant involuntary risks from air pollution on large proportions of their population.[51,52] Control or prevention of this exposure needs to be recognised as critical to the development of environmental and public-health policy. Even if environmental factors pose relatively small risks of common ailments, but the exposure is widespread and vulnerable groups exist in the exposed population, the public-health impact of air pollution can be significant. Where exposure is universal and where the population is vulnerable the marginal contribution of air pollution can be significant.[53]

Conclusion

Regardless of how or when greenhouse gases alter climate,[54] reducing them now will save lives worldwide by lessening particulate air pollution. The beneficial effects of reduced particulate pollution appear to be far greater in rapidly developing countries than in developed countries, although they are substantial in both regions. The overall scientific challenge is to discern enough from present and past trends to reduce uncertainties, so that an integrated impact assessment can yield useful results. Our analysis should not be misconstrued as precise predictions, but as relative indicators of the magnitude of the effects that are likely to arise under conditions that we have specified in these climate-related scenarios.

The transdisciplinary activity pursued in this assessment provides a systematic framework for the estimation of potentially far-ranging and substantial health impacts in an uncertain future world. This estimate looks beyond the restricted view of environmental health as a local problem,[55] recognising the truly global reach of climate policies. There is a dynamic between being able to predict future impacts and being able to affect policies to avoid those potential impacts. In the 18th century, the philosopher Saint-Simon noted "savoir pour prevoir" and "prevoir pour pouvoir". With knowledge comes the ability to predict. With the ability to predict, comes the power to change those predictions.

Contributors

Devra Lee Davis, World Resources Institute (WRI); Tord Kjellstrom and Rudi Slooff, World Health Organization; and Albert McGartland, Environmental Protection Agency (EPA) organised this study. Analyses were provided by Dwight Atkinson, Wiley Barbour, William Hohenstein, Peter Nagelhout, and Tracey Woodruff, EPA, Frank Divita and Jim Wilson, Pechan Associates; Leland Deck, Abt Associates; and Joel Schwartz, Harvard University School of Public Health. All contributed to the writing of this report.

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Value of natriuretic peptides in assessment of patients with possible new heart failure in primary care

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Summary

Background The reliability of a clinical diagnosis of heart failure in primary care is poor. Concentrations of natriuretic peptides are high in heart failure. This population-based study examined the predictive value of natriuretic peptides in patients with a new primary-care diagnosis of heart failure.

Methods Concentrations of plasma atrial (ANP and N-terminal ANP) and B-type (BNP) natriuretic peptides were measured by radioimmunoassay in 122 consecutive patients referred to a rapid-access heart-failure clinic with a new primary-care diagnosis of heart failure. On the basis of clinical assessment, chest radiography, and transthoracic echocardiography, a panel of three cardiologists decided that 35 (29%) patients met the case definition for new heart failure. ANP and NT-ANP results were available for 117 patients (34 with heart failure) and BNP results for 106 (29 with heart failure).

Findings Geometric mean concentrations of natriuretic peptides were much higher in patients with heart failure than in those with other diagnoses (29·2 *vs* 12·4 pmol/L for ANP; 63·9 *vs* 13·9 pmol/L for BNP; 1187 *vs* 410·6 pmol/L for NT-ANP; all $p<0·001$). At cut-off values chosen to give negative predictive values for heart failure of 98% (ANP ≥18·1 pmol/L, NT-ANP ≥537·6 pmol/L, BNP ≥22·2 pmol/L), the sensitivity, specificity, and positive predictive value for ANP were 97%, 72%, and 55%; for NT-ANP 97%, 66%, and 54%; and for BNP 97%, 84%, and 70%. Addition of ANP or NT-ANP concentration or both did not improve the predictive power of a logistic regression model containing BNP concentration alone.

Interpretation In patients with symptoms suspected by a general practitioner to be due to heart failure, plasma BNP concentration seems to be a useful indicator of which patients are likely to have heart failure and require further clinical assessment.

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Introduction

Heart failure is commonly misdiagnosed, and the validity of the diagnosis in primary care is poor.[1,2] The symptoms are non-specific and the clinical signs, although reasonably specific, are not at all sensitive. Consequently, even experienced physicians disagree on the diagnosis in individual cases, especially when the heart failure is mild.[3]

Natriuretic peptides are released in response to increased intracardiac volume or pressure.[4] They have a natriuretic and vasodilatatory effect and suppress the renin-angiotensin-aldosterone system.[5] A prohormone, stored in the atria, on release is cleaved into the active C-terminal atrial natriuretic peptide (ANP) and the inactive and less rapidly cleared N-terminal atrial natriuretic peptide (NT-ANP). B-type natriuretic peptide (BNP) is secreted mainly by the ventricle. The plasma concentration of these peptides is higher than normal in patients with heart failure and also, but to a lesser extent, in patients with symptomless cardiac impairment.[6–11] Measurements of these peptides could therefore provide valuable information about underlying cardiac function.[5] Previous work has focused on their role in detecting symptomless left-ventricular dysfunction after myocardial infarction,[12,13] but little attention has been paid to the role of the natriuretic peptides in assessment of whether a patient's symptoms are due to heart failure at the time of first presentation to primary care.[14,15] Measurement of natriuretic peptides might indicate whether referral for further cardiological assessment is necessary.

NT-ANP and BNP are more stable than ANP[4,16] and therefore are more suitable for use in primary care. Both of these peptides seem to be more sensitive and specific

Q22.2 What level of reductions in greenhouse gas emissions and in the number of deaths associated with exposure to fine particles will result from EPA's recently promulgated fine particles standard?

A22.2 In the Regulatory Impact Analysis of the revised PM, Ozone and Regional Haze NAAQS, EPA estimated that partial attainment of the new PM 2.5 NAAQS would annually prevent between 3,300 to 15,600 premature deaths.

EPA based the primary NAAQS for fine particles on scientific evidence of adverse health effects from exposure to fine particles. The Administrator did not consider reductions in greenhouse gas emissions when making her decision on the level of the fine particles standard. When the standard is implemented by States, to the extent that sources rely on enhanced energy efficiency and fuel switching to comply with the standard, such compliance strategies would tend to reduce greenhouse gas emissions. At this time, however, the Agency has not determined the magnitude of greenhouse gas reductions that will come as a result of compliance with the fine particle standard. Multiple steps are required before States will even determine which sources will need to be regulated: fine particle monitoring data must be collected, each area's attainment status must be determined, and States must decide on appropriate control strategies. Appendix H of the Regulatory Impact Analysis (RIA) for Ozone, PM, and Regional Haze includes an illustrative analysis for electric power plants, based on the Integrated Planning Model (IPM). EPA uses the IPM model to forecast emissions of several pollutants (NOx, SO2, Hg, and CO2) from such plants if a control program were implemented for one or a combination of such pollutants. The illustrative scenario found in Appendix H assumed a 60% reduction in SO2 beyond levels required by the acid rain program, in concert with specified reductions in NOx, achieved through a cap-and-trade program. The IPM model forecasts base case carbon emissions from the electric power sector as 621 million metric tons (MMT) in 2010; under this control scenario, emissions fall to 589 MMT. It should be emphasized that this is just one illustrative control scenario, and that the level of SO2 reductions needed from electric power sources in order to meet the fine particle standard has yet to be determined, for the reasons explained above.

Q22.3 Please document the figures provided in the response to question 22.2 above.

A22.3 See the Regulatory Impact Analysis of the revised PM, Ozone and Regional Haze NAAQS.

<u>**Other Benefits of Reducing Greenhouse Gases**</u>

Q23. On page 11 of your written testimony, you state:

"In addition to health benefits, greenhouse gas mitigation would lead to improved visibility, more and better recreational opportunities, and reduced nitrogen deposition in vulnerable water bodies (such as the Chesapeake Bay)."

Please document these claims.

A23. Improved visibility, enhanced recreational opportunities and reductions in estuarine nitrogen deposition are identified as benefit categories in the Regulatory Impact Analysis of the revised PM, Ozone and Regional Haze NAAQS. To the extent that greenhouse gas mitigation results in reductions in emissions of PM and its precursors, these benefits would be realized as well. While the qualitative relationship between greenhouse gas mitigation and criteria air pollutant emissions is clear, its quantitative impact has not yet been assessed.

<u>**Reduction of NOx Emissions Due to CCTI Programs**</u>

Q24. On page 11 of your written testimony, you state:

"In 1999, EPA's CCTI programs alone are expected to also reduce NOx emissions by 90,000 tons per year, improving both air and water quality."

Please document these claims.

A24. See attachment, 1998 Budget Narrative.

<u>1999 Annual Performance Goals</u>

- Reduce U.S. greenhouse gas emissions by 40 million metric ton carbon equivalent (MMTCE) per year through partnerships with businesses, schools, state and local governments, and other organizations.

- Improve national air quality through reductions in criteria air pollutants, including annual reductions of over 90,000 tons of nitrogen oxides (NOx), a major contributor to ground-level ozone.

- Reduce U.S. energy consumption by over 45 billion kilowatt hours per year, including annual energy bill savings to consumers and businesses of over $3 billion. Encourage more widespread adoption of low greenhouse gas emitting technologies.

- Work with representatives of companies and industries interested in developing roadmaps of actions in the public and private sectors that can lead to improvements in energy use and reductions in GHG emissions.

- Conduct bilateral dialogues with 10-12 key developing countries to bring them toward meaningful participation under the Kyoto protocol. Reduce greenhouse gas emissions internationally.

- Advance the understanding and communicate the risks of climate change by working with state constituencies to assess economic and environmental impacts, develop strategies for reducing vulnerabilities, build the infrastructure to overcome existing impediments to mitigation, and implement technology-based options.

- Guide the development of the rules and guidelines to operationalize emissions trading, the Clean Development Mechanism, joint implementation, and early reduction credits.

- Assess greenhouse gas implications of major sector-based policies (e.g., utility deregulation, subsidy removal, revenue recycling, land use policy).

- Assess economic and technological advances to evaluate and establish domestic policies and measures to meet U.S. obligations under the Framework Convention on Climate Change and the December 1997 Kyoto Protocol.

- Demonstrate that an American family car can attain over 60 miles per gallon (MPG) on the Federal Test Procedure (FTP) without loss in utility, safely, and emissions control performance.

- Begin process to optimize prototype vehicle and to apply knowledge gained through PNGV program to trucks.

<u>Research</u>

- Develop reports on problem formulation for ecosystem services sector assessment and on the use of climate change indicators.

Continuation of EPA's Existing Climate Change Programs

Q25. During your oral response to a question posed by Representative Morella, you stated that "the existing Climate Change Programs that we have, we have estimated that if we were to continue those through the period that you describe, in essence the next decade, that they would eliminate about 20 percent or so of that gap you identify."

Please document this claim.

A25. See *U.S. Climate Action Report -- 1997* (copy attached). Total greenhouse gas reductions from current CCAP programs, if sustained at current funding, are estimated at 169 mmtce in 2010 (page 82). This is equivalent to more than 20% of the "gap" between projected baseline emissions in 2010, and the Kyoto target.

Clean Air Act Emission Allowances

Q26. Is there anything in the Clean Air Act that would prohibit emissions allowances for electric generating stationary sources being distributed on the basis of the amount of electricity a unit produced, rather than basing it on (sic) type of fuel used?

A26. EPA is not aware of any provisions in the Clean Air Act that would restrict how allowances may be distributed to sources included in a cap-and-trade program (other than the existing title IV SO2 cap-and-trade program), including the use of heat input based allocation systems, electrical output based allocation systems, and auctions.

Fine Particulate Standard and Greenhouse Gas Emission Reductions

Q27. Last week before the Committee, Ms. Katie McGinty, Chair of the Council on Environmental Quality stated that "EPA's recently promulgated fine particulate standard should result in both some reductions in greenhouse gas emissions along with reducing the number of deaths associated with exposure to particulates." How much is the anticipated reduction in greenhouse gases from that standard?

A27. See response to Question 22.2.

Legislative/Regulatory Initiatives to Reduce Greenhouse Gases

Q28. What specific legislative/regulatory initiatives are under consideration by EPA to reduce greenhouse gas emissions?

A28. None.

<u>FY 1999 Climate Change Technology Initiative (CCTI) Funding Details</u>

Q29. **The President's FY 1999 budget request includes $205 million for EPA for the Climate Change Technology Initiative (see Budget of the United States Government, Fiscal Year 1999, Table 6-2, p.96). Table 6-2 also indicates that the EPA's budget included $86 million in FY 1997 and $90 in FY 1998 in similar activities.**

For each of FY 1997, FY 1998 and FY 1999, please provide the funding for each EPA appropriation, NPM, program component, and program element included as part of the Climate Change Technology Initiative (CCTI).

A29. The following table provides the information requested:

Appropriation/ Program Component	FY 1997 Operating Plan	FY 1998 Operating Plan	FY 1999 President's Budget
EPM Account	$69,895,000	$72,478,900	$158,502,100
a) Industry Initiatives	$19,589,800	$20,893,900	$51,600,000
b) Buildings	$37,045,000	$38,785,000	$78,100,000
c) Carbon Removal	---	---	$3,400,000
d) Transportation	$4,474,700	$4,800,000	$12,002,100
e) Engaging Developing Countries	$5,520,600	$5,000,000	$8,400,000
f) State & Local Outreach	$3,264,900	$3,000,000	$5,000,000
S&T Account	$16,408,200	$16,950,700	$46,905,500
a) Transportation-- PNGV Cars, Diesel Light Trucks, Heavy Vehicle Engines	$14,337,100	$15,602,500	$43,661,300
b) Transportation-- Efficiency	$871,100	$1,348,200	$3,244,200
c) Buildings	$1,200,000	---	---
Total	$86,303,200	$89,429,600	$205,407,600

COMMITTEE ON SCIENCE
U.S. HOUSE OF REPRESENTATIVES

Hearing
on

The Road from Kyoto—Part 2:

Kyoto and the Administration's Fiscal Year 1999 Budget Request

Thursday, February 12, 1998

Post-Hearing Questions and Answers
Submitted to

Mr. Gary R. Bachula
Acting Under Secretary for Technology
Technology Administration
U. S. Department of Commerce

U.S. Environmental Industry Revenues and Employment

Q1. Page 4 of your written testimony states that "The latest figures show that as of 1996, the U.S. environmental industry employed 1.3 million Americans and has revenues of over $180 billion. The global market for environmental technologies, which stands today at about $450 billion, is expected to grow to some $600 billion by the year 2010. And as the global market grows, so do U.S. exports of environmental technology—$16 billion in 1996, a 60 percent increase since 1993."

Please document these statements.

A1. The employment, revenue, and export numbers used in the testimony were drawn from the Commerce Department's Office of Technology Policy report entitled, "Meeting the Challenge: U.S. Industry Faces the 21st Century—The Environmental Industry."

The data in this report was drawn from a survey of firms in the industry conducted by Environmental Business International (EBI) in 1997 as part of its annual proprietary survey of the environmental industry. About 1,450 firms of the approximately 2,000 firms that were contacted completed the survey. The research and survey process used by EBI, which has been collecting this data since 1987, was assessed by the Environmental Law Institute on behalf of the Environmental Protection Agency in 1995 and given full endorsement for statistical accuracy. EBI is also the source of the projection of a $600 billion environmental market size by 2010, though this figure is not included in the aforementioned Commerce report.

57-716 99 - 28

<u>Partnership for a New Generation of Vehicles (PNGV)</u>

Q2. From the beginning of the PNGV Program in September 1993, please provide, from Fiscal Year (FY) 1994 through FY 1999, the actual (FY 1994-FY 1997), estimated (FY 1998), and requested (FY 1999) funding by all U.S. Government departments and agencies for the Program by agency, and by appropriation account, program, project and activity.

A2. The first year for which budgets were requested in the context of PNGV was FY 1995, and those figures are the earliest in PNGV's records. Many of the activities in PNGV are continuations of programs that existed prior to the start of the PNGV program. Thus, each agency would have to determine which activities in FY 1994 were "relevant" to PNGV. For FY 1995, we only have records of the most directly-focused R&D programs (Tier 1), although other agencies such as NSF undoubtedly were funding research at levels comparable to recent years' levels; OMB estimates are as shown for NSF and DOT. The figures for both FY 1998 and FY 1999 are now estimated to be $5 million less than the amounts reported in the President's budgets, due to $5 million entries included in DOE's portion of the OMB budget database that appears to be erroneous and are no longer included ($222 million vs. $227 million in FY 1998; $272 million vs. $277 million in FY 1999).

	FY 1995 Approp.	FY1996 Approp.	FY 1997 Approp.	FY 1998 Estimate	FY 1999 Request
Dept. of Energy					
Energy Efficiency – Transportation	90.2	97.8	104.0	116.7	152.6
Energy Efficiency – Industry	1.7	1.0	1.0	1.0	1.0
Energy Research	2.6	7.5	6.0	5.0	5.0
Defense Programs	26.7	13.3	10.0	0	0
Environmental Protection Agency	13.0	14.9	15.0	17.0	35.0
Dept. of Transportation					
NHTSA	0	0	2.5	2.5	4.0
FTA	5.0	5.5	10.0	2.0	0
Dept. of Commerce					
NIST Labs	Not Avail	7.4	6.8	6.5	6.8
ATP	Not Avail	48.5	30.5	17.7	15.0
Technology Admin. (PNGV Secretariat)	0.4	0.5	0.5	0.5	0.5
National Science Foundation	53.0	53.0	56.0	53.0	52.0
TOTAL	**192.6**	**249.4**	**242.3**	**221.9**	**271.9**

Government funding for PNGV is also categorized into three tiers according to the nature of the research.

Tier 1 funding is for R&D that is directly relevant to PNGV's goals and is coordinated with the PNGV Technical Teams. Tier 1 includes the DOE Energy Efficiency and Defense programs, all of the EPA funding (which falls in the Global Climate Change component of their Science and Technology account), the NHTSA funding in DOT, and the DoC Technology Administration's funding for the PNGV Secretariat.

Tier 2 funding is for R&D efforts that are directly relevant to PNGV's goals but are not coordinated through PNGV. The Commerce Department's Advanced Technology Program is a prime example: grants are awarded for automotive-related technologies according to ATP's own criteria, not in direct response to PNGV needs. Meeting PNGV goals is not the primary purpose for the budgeting or awarding of these funds.

Tier 3 funding supports scientific and technological research that will benefit PNGV in the future, but is budgeted and awarded for purposes other than PNGV. This characterizes NSF and NIST laboratory funding and the DOE Energy Research program. The NIST laboratory funding includes the Chemical Science, Manufacturing Engineering, Materials Science, and Physics laboratories. The NSF funding includes estimates from the Engineering and Mathematics and Physical Science Directorates.

Q3. From the beginning of the PNGV Program in September 1993, please provide, from Fiscal Year (FY) 1994 through FY 1999, the actual (FY 1994-FY 1997), estimated (FY 1998), and requested (FY 1999) funding by industry for the Program by industrial entity (e.g., GM, Ford, Chrysler, etc.).

A3. In keeping with the PNGV Declaration of Intent, Chrysler, Ford, General Motors and their suppliers have made significant financial contributions to PNGV cost-shared efforts since the program's inception. On average, over the six fiscal years from 1994 through 1999, industry funding for the program is projected to be equivalent to government funding for all collaborative research efforts governed by cost-shared contracts, cooperative agreements, cooperative research and development agreements with the national laboratories, etc.

In addition to PNGV projects governed by such agreements, both government and industry support many research efforts that do not involve direct collaboration. While these efforts are not cost-shared on a project-by-project basis, they do contribute directly to achieving PNGV goals. For example, a significant portion of the PNGV budget from various federal agencies provides direct funding for in-house national laboratory and university work, which support PNGV. Similarly, the automobile companies and their suppliers spend significant amounts on internal research, development, and vehicle integration projects which are essential to achieving the goals of PNGV. Industry estimates that funding for these activities is equal to or greater than that spent by government for PNGV research and development. Moreover, as the program proceeds toward concept vehicles and production prototypes, industry spending is expected to significantly exceed government spending.

APPENDIX 2: Additional Materials for the Record

The Kyoto Protocol
and the
United Nations Framework Convention on Climate Change

UNITED NATIONS

Framework Convention on Climate Change

Distr.
GENERAL

FCCC/CP/1997/7
18 March 1998

Original: ENGLISH

CONFERENCE OF THE PARTIES

REPORT OF THE CONFERENCE OF THE PARTIES ON ITS THIRD SESSION, HELD AT KYOTO FROM 1 TO 11 DECEMBER 1997

CONTENTS

PART ONE: PROCEEDINGS

Annexes

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* Part Two of this report is contained in document FCCC/CP/1997/7/Add.1.

I. OPENING OF THE SESSION
(Agenda item 1)

1. The third session of the Conference of the Parties to the United Nations Framework Convention on Climate Change, convened pursuant to Article 7.4 of the Convention and decision 1/CP.2, was opened at the Kyoto International Conference Hall, Kyoto, Japan, on 1 December 1997, by the President of the Conference at its second session, Mr. Chen Chimutengwende, Minister of Information, Posts and Telecommunications of Zimbabwe.

A. Statement by the President of the Conference at its second session
(Agenda item 1 (a))

2. The President of the Conference at its second session welcomed all participants to the third session of the Conference of the Parties and thanked the Government of Japan for the excellent facilities it had provided. He said that, since the second session of the Conference, climate change had been the subject of growing worldwide attention and media coverage. The Convention process itself had also made considerable progress, mainly through the work of the subsidiary bodies. The Ad Hoc Group on the Berlin Mandate (AGBM), in particular, had arrived step by step at a consolidated negotiating text for a protocol or another legal instrument, prepared by the Chairman. The adoption of such a protocol or instrument reflecting the principles of equity, justice and fair play constituted the greatest challenge of the current session.

3. Global warming was already happening and the climate system might well be taking an irreversible path unless action was taken immediately. While climate change constituted a threat to each and every individual nation in the world, its impact was likely to be more severe in the developing countries that were least able to cope with the consequences. It was the responsibility of the industrialized nations that had indirectly placed burdens on the rest of the world to take the lead in meeting existing commitments, in reducing emissions and in alleviating human suffering caused by climate change. It was a question of survival for small island States and other low-lying areas of the world and for vulnerable communities in other poor countries. Developing countries were already making efforts domestically, with their limited resources, to attain sustainable economic development and it was not possible for those countries to take on new commitments under the new instrument. In the interests of equity, binding commitments for non-Annex I Parties could not even be envisaged until agreement had been reached on a fair system of apportionment of emission limits, a globally agreed reduction pathway and a projected sustainable future emission level on an equitable basis, and until there was reliable and predictable financial provision for the acquisition and adaptation of sound technologies, know-how and production systems in developing countries.

4. In conclusion, he reported to the Conference of the Parties on the outcome of the informal consultations which he had undertaken in the intersessional period on the draft rules of procedure and the composition of the Bureau. Thanking all those who had co-operated with him during his term of office, and extending his best wishes to the new President, he expressed the hope that the session would prove to be a success and a landmark in the annals of international cooperation.

B. Election of the President of the Conference at its third session
(Agenda item 1 (b))

5. At the 1st plenary meeting, on 1 December, on the proposal of the outgoing President, the Conference of the Parties elected by acclamation Mr. Hiroshi Ohki, Minister of State, Director-General of the Environment Agency, Minister in Charge of Global Environmental Problems of Japan, as its President.

C. Statement by the President
(Agenda item 1 (c))

6. On assuming office, the President welcomed all participants to the third session of the Conference of the Parties and paid tribute to the outgoing President and the Chairman of the AGBM for their important contributions to the Convention process. He also thanked the Executive Secretary and the secretariat for their work in preparing for the present session of the Conference. The most important task facing the Conference of the Parties was to establish a more concrete international framework for the protection of the global climate through the adoption of a protocol to the Convention or another form of legal instrument. Climate change was one of the most serious global environmental issues facing the world today and only a fully worldwide strategy could effectively address the problem. Such a strategy should be based on three principles: developed countries should take the lead now in committing themselves to reduce greenhouse gas emissions below 1990 levels; developing countries should also take actions to address the issue of climate change in promoting their sustainable development, taking into account their common but differentiated responsibilities under the Convention and their respective capabilities; and developed countries should strengthen their partnership with developing countries through the provision of financial and technological support for mitigating global greenhouse gas emissions.

7. There were a large number of outstanding issues to be resolved and he called upon all Parties to work together in a spirit of cooperation and compromise, urging the developed countries with the greatest economic capacity in particular to demonstrate such spirit and leadership in action. In conclusion, he stressed the need to discuss future steps to be taken after the Kyoto Conference for the effective implementation of the protocol and other measures to attain the objective of the Convention. All the climate change problems could not be solved at Kyoto; there was still a long way to go and many more negotiations would have to follow. By reaching agreement at Kyoto, however, the international community could take a definite first step towards promoting climate protection policies for the twenty-first century. It was his earnest hope that, here in Kyoto, where some of the most important events in Japan's history had taken place, it would prove possible to reach another historic decision to protect the world's environment and to secure a sustainable basis for the future prosperity of all mankind.

D. Addresses of welcome
(Agenda item 1 (d))

8. Mr. Keizo Obuchi, Minister for Foreign Affairs of Japan, speaking on behalf of the Government of Japan, welcomed all participants to Kyoto, the ancient capital of Japan, for the third session of the Conference of the Parties. He said that the problem of global warming was rapidly becoming more acute, with severe consequences not only for future generations but also for the world's ecosystems. It was the present generation's historic responsibility to determine the future shape of the earth that it would hand over to future generations. The Kyoto Conference was a crucial opportunity to take a global decision on the extent to which greenhouse gas emissions could be limited in order to combat global warming after the year 2000. Agreement needed to be reached on legally-binding emission reduction targets for developed country Parties. At the same time, developing countries should be asked to make every effort, in their future development activities, to take into account the future of the whole world. To that end, appropriate assistance from developed countries was indispensable. In conclusion, he expressed his earnest hope that the Conference would be able to reach the final agreement the world was waiting for

9. Mr. Teiichi Aramaki, Governor of the Prefecture of Kyoto, welcomed all participants to the third session of the Conference of the Parties, on behalf of all the residents of the Kyoto Prefecture. He said that global warming was one of the most serious environmental problems facing the world today, and that the third session of the Conference of the Parties might well be an important step in tackling global warming in the coming century through the united efforts of all the peoples of the world. For its part, the Kyoto Prefecture had prepared various action programmes to protect the environment, based on the active involvement of local people, business circles, administrative bodies and tourists. and the present Conference provided an opportunity to enhance the local population's awareness of global environmental issues and thus further promote such activities. In conclusion, he wished the Conference every success in arriving at a Kyoto Protocol that would prove to be a landmark in international cooperation for preserving the global environment.

10. Mr. Morikane Masumoto, Mayor of Kyoto, speaking on behalf of all the citizens of Kyoto, welcomed the participants in the Conference to the host city of Kyoto. With a history and tradition of more than 1,200 years, Kyoto was called "a place dear to the heart of every Japanese": The Mayor expressed his delight in the thought that all the participants would have an opportunity to experience the beautiful nature and culture of Kyoto, a world-famous ancient city. Recognizing that the earth was now suffering from damage that humankind alone had caused, the Mayor stressed that it was humankind's responsibility to save the suffering earth, restore the global environment and hand it over to future generations. Since July 1996, when the decision to hold the Conference in Kyoto was taken, the City of Kyoto had organized more than 120 events and projects to raise the citizens' awareness of the urgency of combatting global warming and of the significance of the present Conference. The City of Kyoto had also drawn up a Kyoto City Regional Promotion Plan to help stop global warming, with the aim of reducing CO_2 emissions. To implement that programme, the Miyako Agenda 21 action plan had been drafted. In

conclusion, the Mayor expressed his earnest hope that the Conference would reach a successful agreement with the adoption of an effective Kyoto Protocol.

E. Statement by the Executive Secretary
(Agenda item 1 (e))

11. At the 1st plenary meeting, on 1 December, the Executive Secretary, welcoming all participants to the third session of the Conference of the Parties and thanking the Government of Japan and the Kyoto authorities for all they had done to help the secretariat to put the arrangements for the Conference in place, stressed the importance of the Conference arriving at a well-designed end product that could be successfully sold not only to legislators and tax payers, but also to investors, producers and consumers. The responsibility for investments and other actions that would lead to the limitation and reduction of greenhouse gas emissions would fall primarily on non-governmental actors, in particular the business community. For the business community to be able to respond in a responsible manner, it was essential that the goals, and the rules of the game for achieving them, were clearly defined by Governments. The Conference must also direct its message to the citizens of the world in order to mobilize support for practical actions by communities and local governments to mitigate greenhouse gas emissions. Finally, the message from Kyoto should clearly indicate that it was only through the example of enlightened leadership by the industrialized countries, and by the transnational corporations that were shaping the world economy, that a truly global coalition to combat climate change could be formed, in which all would participate according to their own capacities. He looked forward to a clear, binding and verifiable commitment by the industrialized countries to reduce their emissions below 1990 levels early in the next century, a commitment that would trigger the development and diffusion of new practices, new standards, new technologies and new consumption patterns. Such a result would start to steer the world economy towards a sustainable future.

F. Other statements

12. At the 1st plenary meeting, on 1 December, general statements were made by the representatives of the United Republic of Tanzania (on behalf of the Group of 77 and China), Luxembourg (on behalf of the European Community and its member States), the Russian Federation and the United States of America. At the 2nd plenary meeting, on 1 December, general statements were made by the representatives of Egypt (on behalf of the African Group) and Samoa (on behalf of the Alliance of Small Island States). At the 3rd plenary meeting, on 3 December, a general statement was made by the representative of Slovenia (on behalf of the Group of Central and Eastern European States).

II. ORGANIZATIONAL MATTERS
(Agenda item 2)

A. Status of ratification of the Convention
(Agenda item 2 (a))

13. For its consideration of this sub-item at its 1st plenary meeting, on 1 December, the Conference of the Parties had before it an information document on the status of ratification of the Convention (FCCC/CP/1997/INF.2). On the invitation of the President, the Conference of the Parties took note with satisfaction that, as of 1 December 1997, 167 States and one regional economic integration organization were Parties to the Convention, and took note of the information on the status of ratification contained in document FCCC/CP/1997/INF.2.

14. At the 4th plenary meeting, on 3 December, the representative of Croatia formally objected to the participation of the representative of the Federal Republic of Yugoslavia in the third session of the Conference of the Parties, and to the inclusion of the name of Yugoslavia in the list of Parties in document FCCC/CP/1997/INF.2. He said that the Federal Republic of Yugoslavia was not a member State of the United Nations and thus, in accordance with Article 20 of the Convention, was not entitled to become a Party to the Convention. He therefore requested the presidency to ensure that the representative of the Federal Republic of Yugoslavia did not participate in the meetings of the Conference of the Parties.

15. The Executive Secretary explained that the list of Parties in document FCCC/CP/1997/INF.2 was based on information received from the Secretary-General of the United Nations as Depositary of the Convention. On 10 September 1997 the secretariat had received a communication from the Chief of the Treaty Section advising it of the deposit of an instrument of ratification by Yugoslavia on 3 September 1997. On 24 November 1997 the secretariat had received a copy of a depositary notification from the Legal Office of the United Nations, which conveyed the same information to the Ministries of Foreign Affairs of all Parties and which stated that, in accordance with Article 23.2, Yugoslavia would become a Party to the Convention on 2 December 1997. He informed the Conference of the Parties that he would seek the advice of the Depositary of the Convention on the issue raised.

16. The representatives of Mauritania, Morocco (speaking as Chairman of the Islamic Conference), Luxembourg (speaking on behalf of the European Community and its member States), Pakistan and the United States of America, all supported the request made by the representative of Croatia. The representatives of Georgia and of the Russian Federation, on the other hand, expressed their support for participation by the Federal Republic of Yugoslavia.

17. At the same meeting, the presiding Vice-President requested the representative of the Federal Republic of Yugoslavia to refrain from participating in the proceedings of the Conference pending receipt of legal advice from the Depositary.

18. At the 5th plenary meeting, on 5 December, the Executive Secretary informed the Conference of the Parties that a legal opinion had been received from the Legal Counsel of the

United Nations. In that opinion, the Legal Counsel had explained that, at the time of the signature of the Convention by the Federal Republic of Yugoslavia on 8 June 1992, no decision on its status having been taken by the General Assembly, the Secretariat had not questioned the membership of Yugoslavia in the United Nations and its participation in treaties negotiated under United Nations auspices. It was on that basis that the Secretariat had accepted the signature. The Legal Counsel also had taken the view in 1992 that General Assembly resolution 47/1 had not terminated or suspended Yugoslavia's membership in the United Nations. As regards the acceptance on 3 September 1997 of the deposit by the Federal Republic of Yugoslavia of an instrument of ratification of the Convention, that was not based on a treaty action taken by the former Socialist Federal Republic of Yugoslavia, but rather on the signature of the Convention by a representative of the Federal Republic of Yugoslavia. As General Assembly resolution 47/1, as consistently interpreted by the Secretariat, had not terminated or suspended Yugoslavia's membership in the United Nations, the Depositary had not been in a position not to accept the deposit of an instrument of ratification pursuant to Article 22 of the Convention. The capacity of the Federal Republic of Yugoslavia to participate in meetings of treaty bodies needed to be determined by the relevant treaty bodies themselves. It was thus for the Conference of the Parties itself to take a decision on the participation of the Federal Republic of Yugoslavia in UNFCCC meetings, if it so wished. Some other treaty bodies had taken action to exclude the representatives of the Federal Republic of Yugoslavia from participating in a particular meeting or session, but had avoided dealing with the larger legal issue of its treaty status.

19. The President, pointing out that the opinion of the Legal Counsel was consistent with the request made by the Vice-President presiding over the 4th plenary meeting, ruled that the request to the delegation of the Federal Republic of Yugoslavia to refrain from participating in the proceedings of the Conference should be maintained.

B. Adoption of the rules of procedure
(Agenda item 2 (b))

20. For its consideration of this sub-item at its 1st plenary meeting, on 1 December, the Conference of the Parties had before it the draft rules of procedure, as currently being applied (FCCC/CP/1996/2) and a report by the President of the Conference at its second session on his informal consultations on the draft rules of procedure (FCCC/CP/1997/5). Annex I to that report contained the text of a draft decision on adoption of the rules of procedure, proposed by the President of the Conference at its second session, whereby the Conference would adopt the rules of procedure annexed to that decision, with the exception of draft rule 22, paragraph 1, and draft rule 42, paragraph 1, on the understanding that draft rule 22, paragraph 1, would continue to be applied.

21. Statements were made by representatives of seven Parties, including one speaking on behalf of the Group of 77 and China, one speaking on behalf of the Alliance of Small Island States and one speaking on behalf of the European Community and its member States. In the absence of a consensus on that draft decision, the President proposed, and the Conference of the Parties agreed, that consideration of the sub-item should be postponed to give time for further

consultations. The President ruled that the draft rules of procedure as contained in document FCCC/CP/1996/2 should continue to be applied, with the exception of draft rule 42.

22. At the 12th plenary meeting, on 11 December, the Conference of the Parties, on the proposal of the President, decided that adoption of the rules of procedure should be placed on the agenda for the fourth session of the Conference. The President indicated that, if he sensed a move towards a compromise on that issue, he would undertake further consultations and report back to the Conference of the Parties at its fourth session.

C. Adoption of the agenda
(Agenda item 2 (c))

23. For its consideration of this sub-item at its 1st plenary meeting, on 1 December, the Conference of the Parties had before it a note by the Executive Secretary containing the provisional agenda and annotations (FCCC/CP/1997/1 and Add.1-2) and a proposal by the Group of 77 and China in relation to item 6 of the provisional agenda (FCCC/CP/1997/L.1), listing issues for the focus of the high-level segment attended by ministers and other heads of delegation.

24. At the same meeting, on 1 December, the Conference of the Parties adopted the following agenda:

1. Opening of the session:

   (a) Statement by the President of the Conference at its second session;

   (b) Election of the President of the Conference at its third session;

   (c) Statement by the President;

   (d) Addresses of welcome;

   (e) Statement by the Executive Secretary

2. Organizational matters:

   (a) Status of ratification of the Convention;

   (b) Adoption of the rules of procedure;

   (c) Adoption of the agenda;

   (d) Election of officers other than the President;

   (e) Admission of organizations as observers;

(f) Organization of work, including the establishment of a sessional Committee of the Whole;

(g) Calendar of meetings of Convention bodies 1998-1999;

(h) Date and venue of the fourth session of the Conference of the Parties;

(i) Adoption of the report on credentials.

3. Review of the implementation of the Convention:

(a) Reports of the subsidiary bodies and matters arising therefrom:

(i) Reports of the Subsidiary Body for Scientific and Technological Advice;

(ii) Reports of the Subsidiary Body for Implementation;

(iii) Reports of the Ad Hoc Group on the Berlin Mandate;

(iv) Reports of the Ad Hoc Group on Article 13;

(b) Development and transfer of technologies;

(c) Financial mechanism: report of the Global Environment Facility to the Conference;

(d) Second review of the adequacy of Article 4.2(a) and (b);

(e) Review of information and possible decisions under Article 4.2(f);

(f) Other matters relating to implementation.

4. Amendments to the Convention and its Annexes:

(a) Proposal to amend Article 4.3;

(b) Proposal to amend Article 17;

(c) Proposals to amend Annexes I and II.

5. Adoption of a protocol or another legal instrument: fulfilment of the Berlin Mandate.

6. High-level segment attended by ministers and other heads of delegation.

7. Other matters.

8. Conclusion of the session:

   (a) Adoption of the report of the Conference of the Parties on its third session;

   (b) Closure of the session.

D. Election of officers other than the President
(Agenda item 2 (d))

25. At its 1st plenary meeting, on 1 December, on the proposal of the President, the Conference of the Parties elected by acclamation seven Vice-Presidents and the Rapporteur of the Conference, the Chairman of the Subsidiary Body for Scientific and Technological Advice and the Chairman of the Subsidiary Body for Implementation. The Bureau of the Conference was thus constituted as follows:

President

Mr. Hiroshi Ohki (Japan)

Vice-Presidents

Mr. Anthony Clarke (Canada)
Mr. Tengiz Gzirishvili (Georgia)
Ms. Cornelia Quennet-Thielen (Germany)
Mr. George Manful (Ghana)
Mr. Sergio Zelaya Bonilla (Honduras)
Mr. Espen Ronneberg (Marshall Islands)
Mr. Luis Herrera Marcano (Venezuela)

Rapporteur

Mr. Maciej Sadowski (Poland)

Chairman of the Subsidiary Body for Scientific and Technological Advice

Mr. Kok Kee Chow (Malaysia)

Chairman of the Subsidiary Body for Implementation

Mr. Bakary Kante (Senegal)

26. The Conference of the Parties agreed, on the proposal of the President, that consultations should continue with regard to nominations for the posts of vice-chairpersons and rapporteurs of the subsidiary bodies, with a view to their election at the next sessions of those bodies.

27. At its 2nd meeting, on 1 December, the Conference of the Parties elected Mr. Raúl Estrada-Oyuela (Argentina) as Chairman of the sessional Committee of the Whole and invited him to participate in the meetings of the Bureau of the Conference.

E. Admission of organizations as observers
(Agenda item 2 (e))

28. For its consideration of this sub-item at its 1st plenary meeting, on 1 December, the Conference of the Parties had before it a note by the secretariat on the admission of organizations as observers (FCCC/CP/1997/4), to which was annexed a list of intergovernmental and non-governmental organizations which had expressed their wish to be admitted as observers at the third session of the Conference of the Parties. Pursuant to a recommendation by the Bureau of the Conference, which had reviewed the list of applicant organizations during the October 1997 sessions of the subsidiary bodies, the Conference of the Parties decided to admit as observers to its third session the non-governmental organizations which had an asterisk against their names, and to accord observer status to the intergovernmental and remaining non-governmental organizations in that list. (See annex II of this document.)

F. Organization of work, including the establishment of a sessional Committee of the Whole
(Agenda item 2 (f))

29. In introducing this sub-item, at the 2nd plenary meeting, on 1 December, the President recalled that under Article 7.2 of the Convention the Conference of the Parties, as the supreme body of the Convention, was mandated to keep under regular review the implementation of the Convention and to make, within its mandate, the decisions necessary to promote the effective implementation of the Convention. Furthermore, Article 7.2(a) provided for the Conference of the Parties to periodically examine the obligations of the Parties and the institutional arrangements under the Convention, in light of the objective of the Convention, the experience gained in its implementation, and the evolution of scientific and technological knowledge. In that context, the principal objective of the Conference of the Parties at its third session was to fulfil the Berlin Mandate, set by its decision 1/CP.1, on the basis of the work of the AGBM. In addition, the Conference of the Parties would also consider for the first time amendments to the Convention proposed by Parties.

30. At the same meeting, the Conference of the Parties, pursuant to a recommendation by the SBI at its fifth session (FCCC/SBI/1997/6, para. 44 (c) (ii)), established a sessional Committee of the Whole, open to all delegations, to undertake consideration of agenda item 5 on fulfilment of the Berlin Mandate, and requested the Chairman of the Committee of the Whole to report to the plenary on the results of the Committee's work on Friday, 5 December. All remaining items were allocated to the plenary of the Conference. The Conference of the Parties, on the proposal

of the President, further decided that, of the issues reported to be outstanding by the Chairman of the AGBM (see paragraph 55 below), those relating to the methodologies to be used to estimate emissions by sources and removals by sinks in the new instrument, and preparations for the first meeting of the Parties to the Protocol, should be considered by the Committee of the Whole in connection with agenda item 5, and the issue relating to elements of the Brazilian proposal contained in document FCCC/AGBM/1997/MISC.1/Add.3 should be taken up by the plenary of the Conference under agenda item 3 (f). After an extensive discussion, the President indicated that he would undertake consultations on the question of how to deal with the issue relating to the future development of the commitments of all Parties.

31. With regard to agenda item 6, the President recalled that the purpose of the high-level segment, as defined by the SBI at its sixth session, was to promote decision-making (FCCC/SBI/1997/16, para. 34 (g)). It would mark the conclusion of the work of the sessional Committee of the Whole, and the handover of the negotiating process to ministers and other heads of delegation and their senior advisers for the final days of work before the adoption of a new instrument. The high-level segment would be marked by a series of intensive informal consultations as well as a general debate in the plenary.

32. On the proposal of the President, the Conference of the Parties decided that, during the general debate, the time limit for statements should be set at five minutes for statements by representatives of Parties and at four minutes for all other statements. It also decided that the list of speakers should be officially closed at 18.00 hours on Wednesday, 3 December.

33. At the same meeting, the Executive Secretary, referring to the report on the status of contributions to the core budget for the biennium 1996-1997 (FCCC/CP/1997/INF.4), appealed to all Parties that had not yet paid their 1996 or 1997 contributions to the core budget to do so as soon as possible, and expressed his appreciation to those Parties that had paid their contributions promptly and, in particular, to those Parties that had pledged additional amounts to the Trust Fund for Participation. The President endorsed the statement made by the Executive Secretary and added his full support to his plea for Parties with contributions still in arrears to remit their payments as soon as possible. At the 4th and 5th plenary meetings, on 3 and 5 December, the Executive Secretary gave further information on the receipt of contributions to the core budget.

34. At its 5th plenary meeting, on 5 December, the Conference of the Parties, having heard an interim report by the Chairman of the Committee of the Whole (see paragraph 77 below), requested the Committee of the Whole to complete its work by the end of Monday, 8 December. At the same meeting, it was agreed that there would be no need to take up agenda item 7, "Other matters".

G. Calendar of meetings of Convention bodies 1998-1999
(Agenda item 2 (g))

35. At its 5th plenary meeting, on 5 December, the Conference of the Parties, on the proposal of the President, adopted the following calendar of meetings of Convention bodies in 1998-1999:

(a) First sessional period in 1998: from 2 to 12 June;

(b) Second sessional period in 1998: from 2 to 13 November;

(c) First sessional period in 1999: from 31 May to 11 June;

(d) Second sessional period in 1999: from 25 October to 5 November.

H. Date and venue of the fourth session of the Conference of the Parties
(Agenda item 2 (h))

36. At the 5th plenary meeting, on 5 December, the President recalled that, in the absence of any offer from a Party to host the fourth session of the Conference of the Parties, the SBI, at its 7th session, had recommended a draft decision for adoption by the Conference of the Parties at the present session, which provided for the fourth session to be held in Bonn in November 1998 (see FCCC/SBI/1997/21, annex I, 7). The representative of Argentina conveyed his Government's invitation to the Conference of the Parties to hold its fourth session in Buenos Aires.

37. At the same meeting, the Conference of the Parties, having considered a proposal by the President (FCCC/CP/1997/L.2), adopted by acclamation decision 5/CP.3 on the date and venue of the fourth session of the Conference of the Parties. For the text of this decision, see Part Two, section I, of this report.

38. The President, on behalf of the Conference of the Parties, extended his sincere thanks to the Government of Argentina for its generous offer to host the fourth session of the Conference of the Parties. Such an offer truly underlined the commitment of the Government of Argentina to the Convention and the Convention process. The Executive Secretary expressed his appreciation to the Government of Argentina for its generous offer and said that he and his colleagues in the secretariat were looking forward to working closely with the Argentine authorities in the preparations for the fourth session of the Conference of the Parties.

I. Adoption of the report on credentials
(Agenda item 2 (i))

39. At its 12th plenary meeting, on 11 December, the Conference of the Parties took note of the report of the Bureau on the credentials of the representatives of Parties to the third session of the Conference of the Parties (FCCC/CP/1997/6), as orally amended by the Executive Secretary.

J. Attendance

40. The third session of the Conference of the Parties was attended by representatives of the following 158 Parties to the United Nations Framework Convention on Climate Change:

Albania
Algeria
Antigua and Barbuda
Argentina
Armenia
Australia
Austria
Azerbaijan
Bahamas
Bahrain
Bangladesh
Barbados
Belgium
Belize
Benin
Bhutan
Bolivia
Botswana
Brazil
Bulgaria
Burkina Faso
Burundi
Cambodia
Cameroon
Canada
Cape Verde
Central African Republic
Chile
China
Colombia
Comoros
Congo
Cook Islands
Costa Rica
Côte d'Ivoire
Croatia
Cuba
Czech Republic
Democratic Republic of the Congo
Denmark
Djibouti
Dominica
Ecuador
Egypt
El Salvador
Eritrea
Estonia
Ethiopia
European Community
Fiji
Finland
France
Gambia
Georgia
Germany
Ghana
Greece
Grenada
Guatemala
Guinea
Guinea-Bissau
Honduras
Hungary
Iceland
India
Indonesia
Iran (Islamic Republic of)
Ireland
Israel
Italy
Jamaica
Japan
Jordan
Kazakstan
Kenya
Kiribati
Kuwait
Lao People's Democratic Republic
Latvia
Lebanon
Lesotho
Liechtenstein
Lithuania
Luxembourg
Malawi
Malaysia
Maldives
Mali
Malta
Marshall Islands
Mauritania
Mauritius
Mexico
Micronesia (Federated States of)
Monaco
Mongolia
Morocco
Mozambique
Myanmar
Nauru
Nepal
Netherlands
New Zealand
Nicaragua
Niger
Niue
Norway
Pakistan
Panama
Papua New Guinea
Paraguay
Peru
Philippines
Poland
Portugal
Qatar
Republic of Korea

Romania
Russian Federation
Saint Kitts and Nevis
Saint Lucia
Samoa
Saudi Arabia
Senegal
Seychelles
Singapore
Slovakia
Slovenia
Solomon Islands
South Africa
Spain
Sri Lanka
Sudan
Swaziland
Sweden
Switzerland
Syrian Arab Republic
Thailand
Togo
Trinidad and Tobago
Tunisia
Turkmenistan
Tuvalu
Uganda
Ukraine
United Arab Emirates
United Kingdom of Great Britain and Northern Ireland
United Republic of Tanzania
United States of America
Uruguay
Uzbekistan
Vanuatu
Venezuela
Viet Nam
Yemen
Yugoslavia
Zambia
Zimbabwe

41. The session was also attended by observers from the following States not parties to the Convention: Belarus, Brunei Darussalam, Holy See, Libyan Arab Jamahiriya, Palau and Turkey.

42. The following United Nations offices and programmes were represented:

United Nations
Economic and Social Commission for Asia and the Pacific (ESCAP)
United Nations Conference on Trade and Development (UNCTAD)
United Nations Development Programme (UNDP)
United Nations Environment Programme (UNEP)
World Food Programme (WFP)
United Nations University, Institute of Advanced Studies
United Nations Institute for Training and Research (UNITAR)
United Nations Non-Governmental Liaison Service
Convention to Combat Desertification (CCD).

43. The following specialized agencies and other organizations of the United Nations system were represented:

United Nations Educational, Scientific and Cultural Organization (UNESCO)
Intergovernmental Oceanographic Commission (UNESCO/IOC)
International Civil Aviation Organization (ICAO)
World Health Organization (WHO)
World Bank
World Bank/International Finance Corporation (IFC)
Global Environment Facility of the World Bank/UNDP/UNEP (GEF)
World Meteorological Organization (WMO)
WMO/UNEP Intergovernmental Panel on Climate Change (IPCC)

International Maritime Organization (IMO)
United Nations Industrial Development Organization (UNIDO)
International Atomic Energy Organization (IAEA)
World Trade Organization (WTO)

44. For a list of the intergovernmental and non-governmental organizations attending the Conference, see annex II below.

K. Documentation

45. The documents before the Conference of the Parties at its third session are listed in annex III below.

III. REVIEW OF THE IMPLEMENTATION OF THE CONVENTION
(Agenda item 3)

A. Reports of the subsidiary bodies and matters arising therefrom
(Agenda item 3 (a))

1. Reports of the Subsidiary Body for Scientific and Technological Advice
(Agenda item 3 (a) (i))

46. At the 2nd plenary meeting, on 1 December, the Chairman of the Subsidiary Body for Scientific and Technological Advice (SBSTA) introduced the reports of the SBSTA on the work of its fourth, fifth, sixth and seventh sessions, contained in documents FCCC/SBSTA/1996/20 and FCCC/SBSTA/1997/4, 6, and 14, respectively, and reviewed the issues considered by the SBSTA during those sessions. He drew attention to a number of draft decisions which the SBSTA, at its seventh session, had recommended for adoption by the Conference of the Parties at its present session, the texts of which were contained in document FCCC/SBSTA/1997/14, annex I. Two of those draft decisions, relating to the development and transfer of technologies and to activities implemented jointly under the pilot phase, had been recommended for adoption by both the SBSTA and the SBI at their seventh sessions.

47. At the same meeting, the Conference of the Parties took note of the above-mentioned reports of the SBSTA, together with the oral report of the Chairman, and expressed its appreciation to the outgoing Chairman of the SBSTA, Mr. Tibor Faragó (Hungary), for his dedication and valuable leadership in steering the work of the SBSTA. At the same meeting, the Conference of the Parties adopted the following decisions that had been recommended for adoption by the SBSTA:

– Cooperation with the Intergovernmental Panel on Climate Change (decision 7/CP.3)
– Development of observational networks of the climate system (decision 8/CP.3)
– Development and transfer of technologies (decision 9/CP.3)
– Activities implemented jointly under the pilot phase (decision 10/CP.3)

For the texts of these decisions, see Part Two, section I, of this report.

48. In connection with the adoption of decision 7/CP.3 on cooperation with the Intergovernmental Panel on Climate Change, statements were made by the Chairman Emeritus of the IPCC, Professor Bert Bolin, and by the Executive Secretary, the latter expressing appreciation to Professor Bolin on behalf of the secretariat. The President extended his sincere thanks to Professor Bolin, on behalf of the Conference of the Parties, for his noteworthy contributions to the Convention process and for his role in advancing the global understanding of climate change as Chairman of IPCC for almost a decade.

2. Reports of the Subsidiary Body for Implementation
(Agenda item 3 (a) (ii))

49. At the 2nd plenary meeting, on 1 December, the Chairman of the Subsidiary Body for Implementation (SBI) introduced the reports of the SBI on the work of its fourth, fifth, sixth and seventh sessions, contained in documents FCCC/SBI/1996/14 and FCCC/SBI/1997/6, 16 and 21, respectively, and reviewed the issues considered by the SBI during those sessions. He drew attention to a number of draft decisions which the SBI, at its sixth and seventh sessions, had recommended for adoption by the Conference of the Parties at its present session, the texts of which were contained in document FCCC/SBI/1997/21, annex I. One of those draft decisions, relating to the division of labour between the Subsidiary Body for Implementation and the Subsidiary Body for Scientific and Technological Advice, had been jointly recommended by the SBI and the SBSTA. Another draft decision, relating to communications from Parties included in Annex I to the Convention, had been recommended by the SBI but contained an input from the SBSTA.

50. At the same meeting, the Conference of the Parties took note of the above-mentioned reports of the SBI, together with the oral report of the Chairman, and expressed its appreciation to the outgoing Chairman of the SBI, Mr. Mohamed M. Ould El Ghaouth (Mauritania), for his leadership and his valuable contributions to the work of the SBI. At the same meeting, the Conference of the Parties adopted the following decisions that had been recommended for adoption by the SBI:

- Division of labour between the Subsidiary Body for Implementation and the Subsidiary Body for Scientific and Technological Advice (decision 13/CP.3)
- Communications from Parties included in Annex I to the Convention (decision 6/CP.3)
- Volume of documentation (decision 18/CP.3)
- Review of the financial mechanism (decision 11/CP.3)
- Annex to the Memorandum of Understanding on the determination of funding necessary and available for the implementation of the Convention (decision 12/CP.3)
- Financial performance of the Convention in the biennium 1996-1997 (decision 16/CP.3)
- Arrangements for administrative support to the Convention secretariat (decision 17/CP.3)

For the texts of these decisions, see Part Two, section I, of this report.

51. At the 5th plenary meeting, on 5 December, the Conference of the Parties took note of document FCCC/CP/1997/INF.3 on secretariat activities relating to technical and financial support to Parties and document FCCC/CP/1997/INF.1 entitled, "Programme budget of the Convention for the biennium 1998-1999: detailed subprogramme activities and resource requirements".

52. At the 12th plenary meeting, on 11 December, the Conference of the Parties considered a draft decision on the programme budget for the biennium 1998-1999, submitted by the Chairman of the SBI on the basis of his informal consultations (FCCC/CP/1997/L.8). The Executive Secretary, welcoming the incorporation of additional resources for activities related to the Kyoto

Protocol, stated that the secretariat would need to look at the question of how to integrate those activities into its work programme, in particular in respect of the tasks listed in decision 1/CP.3 on the adoption of the Kyoto Protocol, for which preparatory work was needed for consideration by the Conference of the Parties at its fourth session. The Conference of the Parties noted the statement by the Executive Secretary and adopted decision 15/CP.3 on the programme budget for the biennium 1998-1999. For the text of this decision, see Part Two, section I, of this report.

3. Reports of the Ad Hoc Group on the Berlin Mandate
(Agenda item 3 (a) (iii))

53. At the 2nd plenary meeting, on 1 December, the Chairman of the Ad Hoc Group on the Berlin Mandate introduced the reports of the AGBM on the work of its fourth, fifth, sixth, seventh and the first part of its eighth sessions, contained in documents FCCC/AGBM/1996/8 and 11, FCCC/AGBM/1997/3 and Add.1 and Add.1/Corr.1, and FCCC/AGBM/1997/5 and 8, respectively. The final results of the work of the AGBM on a protocol or another legal instrument, as approved by the AGBM at the first part of its eighth session, were contained in the revised text under negotiation (FCCC/CP/1997/2).

54. The Chairman of the AGBM then listed a number of issues which the AGBM had not been able to address fully, and which he had undertaken to bring to the attention of the Conference of the Parties. They included the methodologies to be used to estimate emissions by sources and removals by sinks in the new instrument; preparations for the first meeting of the Parties to the Protocol; elements of a proposal submitted by Brazil and contained in document FCCC/AGBM/1997/MISC.1/Add.3, including a proposed methodology to measure emissions over a period of time in terms of their effect on temperature increase; and the future development of the commitments of all Parties.

55. At the same meeting, the Conference of the Parties took note of the above-mentioned reports of the AGBM, together with the oral report of the Chairman, and expressed its appreciation to Mr. Raúl Estrada-Oyuela (Argentina), Chairman of the AGBM, for his dedicated efforts and his noteworthy contribution to the Berlin Mandate process.

56. At the 5th plenary meeting, on 5 December, the Conference of the Parties took note of the report of the AGBM on the work of the second part of its eighth session (FCCC/AGBM/1997/8/Add.1).

4. Reports of the Ad Hoc Group on Article 13
(Agenda item 3 (a) (iv))

57. At its 2nd plenary meeting, on 1 December, the Conference of the Parties, having heard a report on the work of the Ad Hoc Group on Article 13 from its Chairman, took note with appreciation of the reports of the Ad Hoc Group on its third, fourth and fifth sessions (FCCC/AG13/1996/4 and FCCC/AG13/1997/2 and 4) and, pursuant to the recommendation of the Ad Hoc Group at its fifth session, adopted decision 14/CP.3 on the future work of the Ad Hoc Group on Article 13. For the text of this decision, see Part Two, section I, of this report.

B. Development and transfer of technologies
(Agenda item 3 (b))

58. In introducing this sub-item at the 3rd plenary meeting, on 3 December, the President recalled that the Conference of the Parties had already adopted decision 11/CP.3 on the development and transfer of technologies under sub-item 3 (i) (a) (see paragraphs 46 and 47 above). He noted that, at the request of the Conference of the Parties at its second session, the secretariat had organized a round table on the transfer of technologies and know-how, to be held on the morning of Tuesday, 9 December. A short report on that round table would be made available as a conference room paper.

59. Statements were made under this sub-item by the representatives of eight Parties, including one speaking on behalf of the Group of 77 and China. The President indicated that the subject of the development and transfer of technologies would continue to be under consideration by the SBSTA and the SBI, and would be taken up again by the Conference of the Parties at its fourth session.

60. At the 12th plenary meeting, on 11 December, a representative of the secretariat introduced the report on the round table, which had been circulated under the symbol FCCC/CP/1997/CRP.5.

C. Financial mechanism: report of the Global Environment Facility to the Conference
(Agenda item 3 (c))

61. At the 3rd plenary meeting, on 3 December, the Chief Executive Officer and Chairman of the Global Environment Facility (GEF) made a statement introducing the report of the Global Environment Facility to the Conference of the Parties at its third session (FCCC/CP/1997/3). Statements were made by representatives of 14 Parties, including one speaking on behalf of the Group of 77 and China and one speaking on behalf of the European Community and its member States. The Chief Executive Officer and Chairman of the GEF responded to a number of questions raised in those statements. At the same meeting, the Conference of the Parties expressed its appreciation to the Council of the GEF and took note of the above-mentioned report.

D. Second review of the adequacy of Article 4.2(a) and (b)
(Agenda item 3 (d))

62. In introducing this sub-item at the 3rd plenary meeting, on 3 December, the President recalled that the Conference of the Parties had reviewed Article 4.2(a) and (b) of the Convention at its first session and, having considered that the sub-paragraphs were not adequate, the Conference had agreed, in its decision 1/CP.1 on the Berlin Mandate, to begin a process to enable it to take appropriate action for the period beyond the year 2000, including the strengthening of the commitments of Annex I Parties in Article 4.2(a) and (b) through the adoption of a protocol or another legal instrument at its third session. Article 4.2(d) provided that a second review of

Article 4.2(a) and (b) should take place not later than 31 December 1998, and thereafter at regular intervals determined by the Conference of the Parties, until the objective of the Convention was met. The SBI at its sixth session had requested the secretariat to make all necessary preparations for the Conference of the Parties at its third session to consider the second review of the adequacy of Article 4.2(a) and (b), and had invited the Conference of the Parties to place the second review on the agenda for its fourth session.

63. Statements were made under this sub-item by representatives of six Parties, including one speaking on behalf of the Alliance of Small Island States and one speaking on behalf of the European Community and its member States. At the same meeting, the Conference of the Parties decided to place the issue of the second review of the adequacy of Article 4.2(a) and (b) on the agenda for its fourth session, and to request the subsidiary bodies and the secretariat to make all necessary preparations to facilitate future consideration of that item.

E. Review of information and possible decisions under Article 4.2(f) (Agenda item 3 (e))

64. In introducing this sub-item at the 3rd plenary meeting, on 3 December, the President recalled that Article 4.2(f) of the Convention provided that the Conference of the Parties should review, not later than 31 December 1998, available information with a view to taking decisions regarding such amendments to the lists in Annexes I and II as might be appropriate, with the approval of the Party concerned. The Executive Secretary informed the Conference of the Parties that there were three Parties that had indicated that they wished to be included in Annex I to the Convention: Croatia, the Czech Republic and Slovakia. The latter two Parties had requested that the name of Czechoslovakia be deleted from Annex I the Convention, and that their names should be included in its place. Turkey, which was not yet a party to the Convention, had requested the deletion of its name from Annex I and Annex II to the Convention. A submission by Turkey was before the Conference of the Parties in document FCCC/CP/1997/MISC.3.

65. At the same meeting, the representative of Slovenia informed the Conference of the Parties that his country had notified the Depositary, under Article 4.2(g), of its intention to be bound by Article 4.2(a) and (b) of the Convention.

66. After an exchange of views, in which statements were made by representatives of 11 Parties, including one speaking on behalf of the European Community and its member States, and of one observer State, it was agreed that Mr. Luis Herrera Marcano, Vice-President of the Conference, should hold informal consultations on this sub-item and report back to the plenary of the Conference.

67. At the 5th plenary meeting, on 5 December, Mr. Luis Herrera Marcano, Vice-President of the Conference, reported on the outcome of his consultations and submitted a draft decision relating to the deletion of Czechoslovakia from the list of Parties included in Annex I to the Convention, and the inclusion of Croatia, the Czech Republic, Slovakia and Slovenia in that list (FCCC/CP/1997/L.3). He noted that the names of those countries should be followed by the footnote reference a/, which would link their names to the footnote to Annex I reading "Countries

that are undergoing the process of transition to a market economy." It had not yet proved possible to reach a consensus with regard to the deletion of the name of Turkey from the lists in Annexes I and II to the Convention, and he requested authorization to pursue his consultations on that question.

68. At its 12th plenary meeting, on 11 December, the Conference of the Parties considered an amendment to that decision, submitted by the Vice-President (FCCC/CP/1997/L.3/Add.1), adding the names of Monaco and Liechtenstein to the list of Parties included in Annex I to the Convention, together with a number of oral amendments. It then adopted decision 4/CP.3 on amendments to the list in Annex I to the Convention under Article 4.2(f) of the Convention, the text of which is contained in Part Two, section I, of this report. At the same meeting, it also requested the SBI, at its eighth session, to consider the request to delete the name of Turkey from the lists in Annexes I and II to the Convention, and to present a report to the Conference of the Parties at its fourth session for consideration and definitive action.

F. Other matters relating to implementation
(Agenda item 3 (f))

69. At its 5th plenary meeting, on 5 December, the Conference of the Parties, on the proposal of the President, decided that the proposal presented by Brazil in document FCCC/AGBM/1997/MISC.1/Add.3 should be referred to the SBSTA for its advice regarding the methodological and scientific aspects. It authorized the SBSTA to seek inputs, as appropriate, from its roster of experts and from the IPCC, and requested it to make its advice available to the Conference of the Parties at its fourth session. The representative of Brazil made a statement in connection with that decision.

70. At the same meeting, the representative of New Zealand introduced a proposal relating to the future commitments of all the Parties. Statements were made in that connection by 46 Parties, including one speaking on behalf of the Group of 77 and China, one speaking on behalf of the European Community and its member States, one speaking on behalf of the Southern African Development Commission, and one speaking on behalf of the Arab States. The President then informed the Conference of the Parties that, in view of the wide divergence of views expressed, he would consult further with the Bureau on how to deal with the matter.

IV. AMENDMENTS TO THE CONVENTION AND ITS ANNEXES
(Agenda item 4)

71. For its consideration of this item, the Conference of the Parties had before it a note by the secretariat entitled "Amendments to the Convention or its Annexes" (FCCC/SBI/1997/15), containing a proposal by Pakistan and Azerbaijan for the deletion of Turkey from the lists in Annexes I and II to the Convention, an amendment to Article 17 proposed by the Netherlands on behalf of the European Community and its member States, and an amendment to Article 4.3 proposed by Kuwait. At the 4th plenary meeting, on 3 December, statements were made on this item by representatives of 11 Parties, including one speaking on behalf of the European Community and its member States.

A. <u>Proposal to amend Article 4.3</u>
(Agenda item 4 (a))

72. At the 4th plenary meeting, on 3 December, it was agreed that Mr. Bakary Kante, the Chairman of the SBI, should hold informal consultations on the proposed amendment to Article 4.3, and to report back to the plenary of the Conference on the results of those consultations.

73. At the 5th plenary meeting, on 5 December, the Chairman of the SBI reported that, as it had not proved possible to arrive at a consensus on the proposed amendment, Kuwait had agreed not to pursue its proposal. The representative of Kuwait made a statement confirming that his delegation was willing to withdraw its proposed amendment. The Conference of the Parties noted that the proposal to amend Article 4.3 had been withdrawn.

B. <u>Proposal to amend Article 17</u>
(Agenda item 4 (b))

74. At the 4th plenary meeting, on 3 December, it was agreed that Mr. Sergio Zelaya Bonilla, Vice-President of the Conference, should hold informal consultations on the proposed amendment to Article 17, and to report back to the plenary of the Conference on the results of those consultations.

75. At the 5th plenary meeting, on 5 December, the Vice-President reported that it had not proved possible to arrive at a consensus on the proposed amendment. The representative of the Netherlands, on behalf of the European Community and its member States, stated that, in light of the results of the informal consultations, the European Community and its member States would not pursue its proposal. The Conference of the Parties noted that the proposal to amend Article 17 had been withdrawn.

C. Proposal to amend Annexes I and II
(Agenda item 4 (c))

76. At the 4th plenary meeting, on 3 December, the President noted that this proposal was being dealt with under sub-item 3 (e). For the action taken on this sub-item, see paragraphs 67-68 above.

V. ADOPTION OF A PROTOCOL OR ANOTHER LEGAL INSTRUMENT: FULFILMENT OF THE BERLIN MANDATE
(Agenda item 5)

77. At its 2nd plenary meeting, on 1 December, the Conference of the Parties had allocated consideration of this agenda item to the Committee of the Whole (see paragraph 30 above). At the 5th plenary meeting, on 5 December, the Chairman of the Committee of the Whole made an interim report on the state of the negotiations in the Committee on the draft protocol. Three negotiating groups had been established to deal with specific elements of the text. The first, chaired by Mr. Takao Shibata (Japan), was dealing with the Articles relating to institutions and mechanisms; the second, co-chaired by Mr. John Ashe (Antigua and Barbuda) and Mr. Bo Kjellén (Sweden), was dealing with the Articles on continuing to advance the implementation of existing commitments in Article 4.1 of the Convention and the financial mechanism; and the third, chaired by Mr. Mohamed M. Ould El Ghaouth (Mauritania), was dealing with policies and measures. He himself was conducting negotiations on matters relating to quantified emission limitation and reduction objectives (QELROs). In addition to those negotiating groups, he, and some of the chairmen of the negotiating groups, had requested several delegates to conduct informal consultations on specific issues. The intensive negotiations currently under way were advancing and were beginning to yield results, but the Committee of the Whole would need additional time to resolve many of the outstanding issues so that only a few, key issues would remain for the consideration of ministers during the high-level segment.

78. At the 12th plenary meeting, on 11 December, the Chairman of the Committee of the Whole reported on the outcome of the work of the Committee. The Committee of the Whole had unanimously recommended, for adoption by the Conference of the Parties, a draft decision on the adoption of the Kyoto Protocol to the United Nations Framework Convention on Climate Change (FCCC/CP/1997/L.7), to which the text of the Protocol (FCCC/CP/1997/L.7/Add.1) was annexed. It had also recommended a draft decision on methodological issues related to the Kyoto Protocol (FCCC/CP/1997/L.5) and a draft decision on the implementation of Article 4, paragraphs 8 and 9, of the Convention (FCCC/CP/1997/L.9). The Committee had further recommended that, for the purposes of Article 25 of the Protocol relating to entry into force, a table indicating the total carbon dioxide emissions of Annex I Parties in 1990, to be prepared on the basis of secretariat documents relating to first national communications, should be annexed to the report of the Conference.

79. The President, on behalf of the Conference, expressed his great appreciation of the work accomplished by the Committee of the Whole and paid tribute to the Chairman of that Committee for his untiring efforts and the leadership he had shown throughout the negotiating process. He also thanked the chairmen of the negotiating groups and all those who had assisted the Chairman in the formal and informal consultations.

80. On the advice of the Chairman of the Committee of the Whole, the President proposed an oral amendment to the draft decision on adoption of the Kyoto Protocol contained in FCCC/CP/1997/L.7, adding a further sub-paragraph to operative paragraph 5 of the draft decision. In the ensuing discussion, the representative of a Party suggested an alternative

formulation of the additional sub-paragraph; on the advice of the Chairman of the Committee of the Whole, the President did not propose this text for adoption. Some technical corrections to the text of the Kyoto Protocol were proposed orally and accepted by the President; these deleted paragraph 11 of Article 12 and footnote 1 in Annex B and amended the title of a column in that Annex. The Executive Secretary requested Parties to submit any further technical corrections in writing to the secretariat, so that the final authentic texts of the Protocol could be completed in time for its opening for signature on 16 March 1998.

81. The Conference of the Parties then proceeded to adopt decision 1/CP.3 entitled "Adoption of the Kyoto Protocol to the United Nations Framework Convention on Climate Change", including the oral amendment proposed by the President, thereby adopting the said Protocol which was annexed to that decision. At the same meeting, the Conference also adopted decision 2/CP.3 on methodological issues related to the Kyoto Protocol and decision 3/CP.3 on implementation of Article 4, paragraphs 8 and 9, of the Convention. For the texts of these decisions, see Part Two, section I, of this report. The Conference of the Parties further decided that, for the purposes of Article 25 of the Protocol relating to entry into force, a table indicating the total carbon dioxide emissions of Annex I Parties in 1990, to be prepared on the basis of secretariat documents relating to first national communications, should be annexed to the report of the Conference (see the annex to Part Two of this report).

82. The representative of Luxembourg, speaking on behalf of the European Community and its member States, stated that the European Community and its member States would implement their respective commitments under Article 3, paragraph 1, of the Protocol, in accordance with the provisions of Article 4 of the Protocol.

83. The representative of Trinidad and Tobago, speaking on behalf of the Alliance of Small Island States (AOSIS), recalled that three years had elapsed since AOSIS had first proposed the adoption of a protocol to the Convention which would strengthen the commitments of Annex I Parties and would be capable of sending strong and clear signals to the market place. The reductions agreed upon as a result of the compromises reached in the Kyoto Protocol were inadequate to meet the message of science and the emissions allowed to some countries were, in his view, morally questionable. No country should be allowed to buy its reductions and those Parties which had come to Kyoto prepared to accept greater reductions than those eventually agreed upon should continue their efforts to achieve maximum reductions. Many methodological and scientific uncertainties remained and resources would be needed to tackle them. The aspirations of AOSIS had been largely frustrated and Parties should be prepared to return next year with a clearer purpose, in the knowledge that future generations would have to pay the price of the compromises reached today.

VI. HIGH-LEVEL SEGMENT ATTENDED BY MINISTERS AND OTHER HEADS OF DELEGATION
(Agenda item 6)

84. At the opening of the high-level segment at the 6th plenary meeting, on 8 December, the Conference of the Parties was addressed by Mr. Ryutaro Hashimoto, Prime Minister of Japan; Mr. José Maria Figueres Olsen, President of Costa Rica; Mr. Kinza Clodumar, President of Nauru; Mr. Albert Gore, Jr., Vice President of the United States of America and President of the Senate; and Mr. Maurice F. Strong, representative of the Secretary-General of the United Nations, who delivered a message to the Conference of the Parties on behalf of the Secretary-General.

85. Statements were made by the President of the Conference and by the Executive Secretary at the opening of the general debate. The general debate was held during the 6th, 7th, 8th, 9th, 10th and 11th plenary meetings, on 8 and 9 December. During that debate, statements were made by 124 ministers and other heads of delegation of Parties, by a minister from one observer State, and by representatives of 5 United Nations offices and programmes, 10 specialized agencies and other organizations of the United Nations system, 6 intergovernmental organizations and 12 non-governmental organizations. For the list of speakers in the general debate, see annex I below.

VII. CONCLUSION OF THE SESSION
(Agenda item 8)

A. Adoption of the report of the Conference of the Parties on its third session
(Agenda item 8 (a))

86. At its 12th plenary meeting, on 11 December, the Conference of the Parties adopted the draft report on its third session (FCCC/CP/1997/L.4) and authorized the Rapporteur, with the assistance of the secretariat, to complete the report as appropriate.

B. Closure of the session
(Agenda item 8(b))

87. At its 12th plenary meeting, on 11 December, the Conference of the Parties, having considered a draft resolution submitted by Bhutan (FCCC/CP/1997/L.6), adopted resolution 1/CP.3 entitled "Expression of gratitude to the Government and people of Japan". For the text of this resolution, see Part Two, section II, of this report.

88. Closing statements were made by the representatives of the United States of America, Luxembourg (on behalf of the European Community and its member States), the United Republic of Tanzania (on behalf of the Group of 77 and China) and Japan. A statement was made by the Executive Secretary.

89. The President, after making a closing statement in which he thanked all participants for their constructive cooperation in the negotiations, declared the third session of the Conference of the Parties closed.

Annex I

Statements by ministers and by other representatives during the high-level segment of the third session of the Conference of the Parties: list of speakers

I. Parties to the Convention

		Plenary meeting
Albania	Mr. Maksim Deliana Chairman of the Environmental Protection Committee	8
Algeria	Mr. Bachir Amrat Minister of Environment	10
Argentina	Ms. Maria Julia Alsogaray Secretary for Natural Resources and Human Environment	6
Armenia	Mr. Sarkis Shahazizyan Minister of Nature Protection	10
Australia	Mr. Robert Hill Minister for the Environment	6
Austria	Dr. Martin Bartenstein Federal Minister for the Environment, Youth and Family Affairs	9
Azerbaijan	Mr. Zulfugar Musayev Minister of State responsible for Hydrometeorology and Environment	10
Bahrain	Mr. Khalid M. Fakhro Director-General, Environmental Affairs	11
Bangladesh	Begum Syeda Sajeda Chowdhury Minister for Environment and Forests	7

		Plenary meeting
Barbados[a]	Ms. Elizabeth Thompson Minister of Environment and Health	7
Belgium	Mr. Jan Peeters Federal Minister of the Environment	9
Bhutan	Mr. Dasho Paljor J. Dorji Deputy Minister for Environment	11
Bolivia	Ms. Neisa Roca Hurtado Deputy Minister of Sustainable Development and the Environment	8
Botswana	Mr. Daniel K. Kwelagobe Minister of Works, Transport and Communications	8
Brazil	Mr. José Israel Vargas Minister for Science and Technology	7
Bulgaria	Ms. Evdokia Maneva Minister of Environment and Water	10
Cambodia	Dr. Mok Mareth Minister, Ministry of Environment	10
Canada	Ms. Christine Stewart Minister of the Environment	7
Chile	Mr. Rolando Stein Ambassador, Director of Environment Ministry of Foreign Affairs	11
China	Mr. Yaobang Chen Minister of Forestry and Vice-Chairman of the State Planning Commission	7
Colombia	Mr. Eduardo Verano de la Rosa Minister for the Environment	9

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[a] Speaking also on behalf of the Caribbean Community.

		Plenary meeting
Costa Rica	Mr. José María Figueres Olsen President	6
Côte d'Ivoire	Mr. Albert K. Tiapani Minister for Housing, the Quality of Life and the Environment	10
Croatia	Dr. Ljerka Mintas Hodak Deputy Prime Minister	9
Cuba	Dr. Rosa Elena Simeón Negrín Minister of Science, Technology and the Environment	9
Czech Republic	Mr. Vadislav Bizek Deputy Minister of the Environment	10
Denmark	Mr. Svend Auken Minister of Environment and Energy	7
Ecuador	Mr. Juan Salazar Sancisi Ambassador of Ecuador to Japan	11
Egypt	Ms. Nadia Riad Mekram Ebeid State Minister for the Environment	9
Eritrea	Mr. Tekleab Mesghina Director-General, Department of the Environment, Ministry of Land, Water and the Environment	11
Estonia	Mr. Villu Reiljan Minister of the Environment	10
Ethiopia	Mr. Shiferaw Jarso Minister of Water Resources	10
European Community	Ms. Ritt Bjerregaard Environment Commissioner	7

		Plenary meeting
Fiji	Mr. Seremaia Cavuilati Ambassador of Fiji to Japan Development, Housing and Environment	11
Finland	Mr. Pekka Haavisto Minister of the Environment	9
France	Ms. Dominique Voynet Minister of Physical Planning and the Environment	6
Gambia	Captain Edward Singhatey Secretary of State for Presidential Affairs, Fisheries and Natural Resources	10
Georgia	Ms. Nino Chkhobadze Environment Protection Minister	8
Germany	Dr. Angela Merkel Federal Minister for the Environment, Nature Conservation and Nuclear Safety	7
Ghana	Mr. J. E. Afful Minister for the Environment, Science and Technology	9
Greece	Mr. Theodoros Koliopanos Deputy Minister for the Environment, Physical Planning and Public Works	8
Honduras[b]	Mr. Sergio Alejandro Zelaya Bonilla Vice-Minister of the Environment Ministry of Natural Resources and the Environment	8
Hungary	Dr. Katalin Szili Secretary of State for the Environment	7

[b] Speaking also on behalf of the Central American countries of Belize, Costa Rica, El Salvador, Guatemala, Nicaragua and Panama.

		Plenary meeting
Iceland	Mr. Gudmundur Bjarnason Minister for the Environment	7
India	Prof. Saifuddin Soz Minister for Environment and Forests	6
Indonesia	Mr. Sarwono Kusumaatmadja State Minister for Environment	7
Iran (Islamic Republic of)	Dr. Masoumeh Ebtekar Vice-President and Director of the Department of Environment	6
Ireland	Mr. Noel Dempsey Minister for the Environment and Local Government	9
Italy	Mr. Edo Ronchi Minister for Environment	9
Japan	Mr. Ryutaro Hashimoto Prime Minister	6
	Mr. Keizo Obuchi Minister for Foreign Affairs	6
	Mr. Mitsuo Horiuchi Minister for International Trade and Industry	6
Jordan	Mr. Farouk Kasrawi Ambassador of Jordan to Japan	11
Kazakhstan	Mr. Serikbek Daukeev Minister of Ecology and Natural Resources	9
Kenya	Mr. William P. Mayaka Permanent Secretary Ministry of Environment and Natural Resources	11
Kiribati	Mr. Tewareka Borau Minister for Environment and Social Development	10

		Plenary meeting
Kuwait	Dr. Mohammad Abderrahman Al-Saraawi Chairman of the Board and Director-General of the Public Authority for Environment	8
Lao People's Democratic Republic	Prof. Souli Nanthavong Minister, President of Science and Technology and Environment Organization	10
Latvia	Mr. Indulis Emsis State Minister for the Environment, Ministry of Environment Protection and Regional Development	9
Lebanon	Mr. Samir Chamma Ambassador of Lebanon to Japan	11
Lesotho	Mrs. H. M. Mhlanga Principal Secretary, Ministry of Natural Resources	11
Lithuania	Mr. Imantas Lazdinis Environmental Protection Minister	8
Luxembourg[c]	Dr Johny Lahure Minister of the Environment	6
Malawi	Mr. Mayinga Mkandawire Minister for Forestry, Fisheries and Environmental Affairs	10
Malaysia	Datuk Law Hieng Ding Minister of Science, Technology and the Environment	7
Maldives	Mr. Abdul Rasheed Hussain Minister of Planning, Human Resources and Environment	7

[c] Speaking also on behalf of the European Community and its member States

		Plenary meeting
Malta	Mr. Saviour F. Borg Permanent Representative of Malta to United Nations Environment Programme, Ministry of Foreign Affairs and the Environment	11
Mauritius	Mr. James Burty David Minister of Local Government and Environment	10
Mexico	Ms. Julia Carabias Lillo Secretary, Environment, Natural Resources and Fisheries	7
Micronesia (Federated States of)	Mr. Leo A. Falcam Vice-President	9
Monaco	Mr. Bernard Fautrier Minister Plenipotentiary	10
Mongolia	Mr. Tsokhio Adyasuren Minister for Nature and Environment	8
Morocco	Mr. Lahoucine Tijani Secretary of State to the Minister for Agriculture, Works and the Environment	10
Mozambique	Mr. Bernardo Ferraz Minister for Coordination of Environmental Affairs	8
Myanmar	Mr. U Soe Win Ambassador of Myanmar to Japan	11
Nauru	Mr. Kinza Clodumar President	6
Netherlands	Mrs. Margaretha de Boer Minister of Housing, Spatial Planning and Environment	7
New Zealand	Mr. Simon Upton Minister for the Environment	7

		Plenary meeting
Niger	Mr. Kimba Hassane Adviser, Executive Secretariat, National Council on the Environment for Sustainable Development	11
Nigeria	Dr. Adegoke Adegoroye Director-General, Chief Executive, Federal Environmental Protection Agency	8
Niue	Mr. Terry Donald Coe Minister for Post and Telecommunications, Meteorological Services and Climate Change, Agriculture, Fisheries and Forestry	8
Norway	Ms. Guro Fjellanger Minister of Environment	7
Pakistan	Mr. Mujahid Husain Ambassador of Pakistan to Japan	8
Papua New Guinea	Mr. Aiwa Olmi Ambassador of Papua New Guinea to Japan	8
Paraguay	Dr. Miguel Angel Solano López Ambassador Extraordinary and Plenipotentiary of Paraguay to Japan	8
Peru	Ms. Agnes Franco Deputy Minister for Industry	11
Philippines	Mr. Victor O. Ramos Secretary, Department of Environment and Natural Resources	9
Poland	Mr. Radoslaw Gawlik Secretary of State Ministry of Environmental Protection, Natural Resources and Forestry	11
Portugal	Dr. Elisa Ferreira Minister of Environment	8

		Plenary meeting
Qatar	Mr. Ali Ben Saeed Al Khayaren Ministry of Municipality Affairs and Agriculture	8
Republic of Korea	Mr. Yeo-Joon Yoon Minister of Environment	7
Republic of Moldova	Mr. Sergiu Fandofan Minister for Environmental Protection	8
Romania	Mr. Eugen Dijmarescu Ambassador of Romania to Japan	11
Russian Federation	Mr. Alexander J. Bedritsky Head of the Federal Service for Hydrometeorology and Environmental Monitoring	6
Samoa[d]	Mr. Tuala Sale Tagaloa Minister of Lands, Survey and Environment	6
Saudi Arabia	Prince Fahad Bin Abdallah Al-Saud Assistant of the Minister for Defense and Aviation and Inspector-General for Civil Aviation	7
Senegal	Mr. P. Abdoulaye Bathily Minister of Environment	9
Seychelles	Mr. Dolor Ernesta Minister for Community Development	8
Singapore	Mr. Yeo Cheow Tong Minister for the Environment	9
Slovakia	Mr. Jozef Zlocha Minister of Environment	10
Slovenia	Dr. Pavel Gantar Minister of Environment and Physical Planning	9

[d] Speaking also on behalf of the Alliance of Small Island States.

		Plenary meeting
Solomon Islands	Mr. Patteson Oti Minister for Foreign Affairs and Trade Relations	10
South Africa	Mr. Peter Mokaba Deputy Minister of Environmental Affairs and Tourism	8
Spain	Ms. Isabel Tocino Minister for the Environment	7
Sudan	Mr. Mohamed El Kadir Abdalla Director, Meteorology General Corporation	11
Swaziland	Mr. Mduduzi Magongo Principal Secretary for Tourism, Environment and Communications	11
Sweden	Ms. Anna Lindh Minister of the Environment	6
Switzerland	Ms. Ruth Dreifuss Federal Councillor, Head of the Federal Department of Home Affairs	6
Syrian Arab Republic	Mr. Abdul Hamid El-Munajed Minister of Environment	8
Thailand	Mr. Porntep Techapaibul Deputy Minister of Science, Technology and Environment	11
Togo	Mr. Komlavi Yao Minister of Environment and Forest Resources	9
Tunisia	Mr. Salah Hannachi Ambassador of Tunisia to Japan	10
Turkmenistan	Mr. Ovezmurat G. Annaev Deputy Minister, Head of Turkmenglavhydromet	10

		Plenary meeting
Tuvalu	Sir Toaripi Lauti Prime Minister's Special Envoy on Climate Change	8
Uganda	Mr. Bwango Apuuli Department of Meteorology The Ministry of Natural Resources	11
Ukraine	Mr. Yuri Kostenko Minister for Environmental Protection and Nuclear Safety	8
United Arab Emirates	Mr. Hamad Abdul Rahman Al Madfa Minister of Health and Chairman of the Federal Environmental Agency	9
United Kingdom of Great Britain and Northern Ireland	Mr. John Prescott, MP Deputy Prime Minister and Secretary of State for the Environment, Trade and the Regions	6
United Republic of Tanzania[e]	Mr. Bakari Mbonde Minister of State, Vice-President's Office of the United Republic of Tanzania	6
United States of America	Mr. Albert Gore, Jr. Vice President	6
Uruguay	Mr. Juan Gabito Zoboli Under-Secretary, Ministry of Housing, Physical Planning and the Environment	11
Uzbekistan	Dr. Victor E. Chub Minister, Chief of Glavgidromet	7
Vanuatu	Mr. Demis Lango Minister of Civil Aviation	8
Venezuela	Mr. Erwin Arrieta Minister of Energy and Mines	6

[e] Speaking also on behalf of the Group of 77 and China.

		Plenary meeting
Viet Nam	Prof. Nguyen Duc Ngu Director-General, Hydrometeorological Service Chairman of the Environment Protection Council	11
Yemen	Mr. Mohsen Al-Hamdani Chairman of the Environment Protection Council	10
Zambia	Mr. William J. Harrington Minister of Environment and Natural Resources	9
Zimbabwe	Mr. Simon Khaya Moyo Minister of Mines, Environment and Tourism	9

II. Observer State

Turkey	Ms. Imren Aykut Minister of Environment	9

III. United Nations offices and programmes

United Nations	Mr. Maurice Strong Representative of the Secretary-General	6
	Mr. Nitin Desai Under-Secretary-General for Economic and Social Affairs	6
United Nations Economic and Social Commission for Asia and the Pacific	Mr. Rezaul Karim Chief, Environment Section, Environment and Natural Resources Management Division	11
United Nations Development Programme	Mr. Anders Wijkman Assistant Administrator Director, Bureau for Development Policy	10
United Nations Environment Programme	Ms. Elizabeth Dowdeswell Executive Director	7

		Plenary meeting
World Food Programme	Mr. Tun Myat Director, Resources and External Relations Division	11
Convention to Combat Desertification	Mr. Hama Arba Diallo Executive Secretary	10

IV. Specialized agencies and other organizations of the United Nations system

United Nations Educational, Scientific, and Cultural Organization	Mr. Gisbert Glaser Director, Bureau for Coordination of Environmental Programmes	11
Intergovernmental Oceanographic Commission	Mr. Gunnar Kullenberg Executive Secretary	11
International Civil Aviation Organization	Mr. John Crayston Coordinator, Air Transport and Environment Programmes	11
World Bank	Mr. Caio Koch-Weser Managing Director	7
Global Environment Facility	Mr. Mohamed T. El-Ashry Chief Executive Officer and Chairman	9
World Meteorological Organization	Prof. G.O.P. Obasi Secretary-General	7
Intergovernmental Panel on Climate Change	Mr. Robert Watson Chairman	9
United Nations Industrial Development Organization	Mr. Robert O. Williams Senior Industrial Development Officer, Environment and Energy Branch	11
International Atomic Energy Agency	Mr. Hans Holger Rogner Head, Planning and Economic Studies Section	11

V. Intergovernmental organizations

		Plenary meeting
Asian Development Bank	Mr. Kazi Jalal Chief, Office of Environment and Social Development	11
European Bank for Reconstruction and Development	Mr. William V. Kennedy Senior Environmental Specialist	11
International Energy Agency	Mr. Robert Priddle Executive Director	9
Organization of the Petroleum Exporting Countries	Mr. Rilwanu Lukman Secretary-General	10
Permanent Commission for the South Pacific	Mr. Nicolas Roncagliolo Higueras Secretary-General	11
South Pacific Regional Environment Programme	Mr. Gerald Miles Head, Environmental Management and Planning Division	11

VI. Non-governmental organizations

Climate Action Network, South East Asia	Mr. Gurmit Singh Coordinator	9
Global Legislators Organisation for a Balanced Environment	Mr. Tom Spencer President	9
International Chamber of Commerce	Mr. Yoshifumi Tsuji Vice-Chairman Japan Federation of Economic Organizations	10
International Confederation of Free Trade Unions	Mr. Stephen Pursey Head, Economic and Social Policy Department	11
International Council for Local Environmental Initiatives	Mr. Takehisa Matsubara Mayor of the City of Nagoya, Japan	6

		Plenary meeting
International Federation of Chemical, Energy, Mine and General Workers' Unions	Mr. Kenneth S. Zinn North American Regional Coordinator,	11
International Youth and Student Movement for the United Nations	Mr. Hirofumi Goto	10
Scientists for Global Responsibility[f]	Ms. Michele Valentine	11
The Business Council for Sustainable Energy	Mr. Michael Marvin Executive Director	10
United States Climate Action Network	Ms. Jennifer Morgan Coordinator	10
World Business Council for Sustainable Development	Mr. Egil Myklebust President and Chief Executive Officer of Norsk Hydro, Norway	9
World Council of Churches	Mr. David Hallman Climate Change Programme Coordinator	11

[f] Speaking on behalf of "The Climate Train".

Annex II

List of intergovernmental and non-governmental organizations attending the third session of the Conference of the Parties

I. Intergovernmental organizations

1. Agency for Cultural and Technical Co-operation
2. Asian Development Bank
3. Caribbean Community Secretariat
4. Central American Commission on the Environment and Development
5. Commission for Environmental Cooperation
6. European Bank for Reconstruction and Development
7. European Conference of Ministers of Transport
8. International Energy Agency
9. International Institute of Refrigeration
10. International Tropical Timber Organization
11. Organisation for Economic Co-operation and Development
12. Organization of the Petroleum Exporting Countries
13. Permanent Commission for the South Pacific
14. Ramsar Convention on Wetlands
15. South Pacific Regional Environment Programme

II. Non-governmental organizations[a]

1. A SEED Europe - Action for Solidarity, Equality, Environment and Development
2. A SEED Japan - Action for Solidarity, Equality, Environment and Development*
3. African Centre for Technology Studies
4. AIESEC Hitotsubashi Local Committee*
5. Alliance for Responsible Atmospheric Policy
6. Alliance for Responsible Environmental Alternatives
7. Alliance Internationale de Tourisme
8. American Federation of Labor and Congress of Industrial Organizations
9. American Portland Cement Alliance
10. American Society of International Law
11. Architectural Institute of Japan*
12. Association Française du Froid/Alliance Froid, Climatisation, Environnement
13. Association of International Research Initiatives for Environmental Studies*

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[a] The non-governmental organizations listed with an asterisk against their names were admitted only to the third session of the Conference of the Parties. Should they wish to continue to participate in the Convention process, they may reapply

14. Association Tunisie Mediterranée Pour Le Développement Durable
15. Atmosphere Action Network in East Asia
16. Australian Aluminium Council
17. Australian Coal Association
18. Berne Declaration
19. Birdlife International
20. Business Council of Australia
21. Canadian Electricity Association
22. Canadian Global Change Program
23. Canadian Vehicle Manufacturers' Association
24. CEDARENA (Environmental and Natural Resources Law Centre)
25. Center for Clean Air Policy
26. Center for International and European Environmental Research (ecologic)
27. Center for International Climate and Environmental Research
28. Center for International Environmental Law
29. Center for Sustainable Development in the Americas
30. Central Research Institute of Electric Power Industry
31. Centre for Applied Studies in International Negotiations
32. Centre for Business and the Environment
33. Church of the Brethren
34. Citizens Alliance for Saving the Atmosphere and Earth
35. Citizens Environmental Foundation*
36. Citizens' Coalition for Economic Justice
37. Citizens' Nuclear Information Center*
38. Clean Energy and Environment Shimada*
39. Climate Action Network - Africa
40. Climate Action Network - Europe
41. Climate Action Network - Latin America
42. Climate Action Network - United Kingdom
43. Climate Action Network South Asia
44. Climate Action Network-Southeast Asia
45. Climate Institute
46. Columbia Earth Institute/Columbia University
47. Competitive Enterprise Institute
48. Confederación Sindical de Comisiones Obreras
49. Construction, Forestry, Mining and Energy Union
50. Development Alternatives
51. E & Co (An Energy Investment Service)
52. Earth Action
53. Earth Council
54. Earth Science and Technology Organization*
55. Ecosystem Conservation Society*
56. Edison Electric Institute
57. Energy 21

58. Environmental Defense Fund
59. Environment Information Center*
60. European Atomic Forum
61. European Business Council for a Sustainable Energy Future
62. European Environmental Bureau
63. European Insulation Manufacturers Association
64. European Round Table of Industrialists
65. European Science and Environment Forum
66. European Wind Energy Association
67. Federal Association of the German Industry
68. Forests Absorbing Carbondioxide Emisson
69. Foundation for International Environmental Law and Development
70. Franciscans International
71. Free University Berlin
72. Friends of the Earth - Japan*
73. Friends of the Earth International
74. German Advisory Council on Global Change
75. German NGO-Forum on Environment & Development
76. Germanwatch
77. Global Climate Coalition
78. Global Commons Institute
79. Global Dynamics Institute
80. Global Environment Centre Foundation*
81. Global Environment Forum-Kansai
82. Global Environmental Action*
83. Global Guardian Trust*
84. Global Industrial and Social Progress Research Institute
85. Global Legislators Organisation for a Balanced Environment
86. Global Network Class "Gakkos"*
87. Globe Japan*
88. Green Cross Japan*
89. Green Earth Organization
90. Green Fingers Society for Environment Protection
91. Green Korea United
92. Greenpeace International
93. GRIP Québec - University of Montréal
94. Industrial Technology Research Institute
95. Industrial Union Department (IUD), AFL-CIO
96. Information Agency of the German Power Plants
97. Institut de recherche sur l'environnement
98. Insurance Industry Initiative for the Environment, in association with UNEP
99. International Academy of the Environment
100. International Center for Environmental Technology Transfer*
101. International Chamber of Commerce

102. International Climate Change Partnership
103. International Confederation of Free Trade Unions
104. International Council for Local Environmental Initiatives
105. International Council of Environmental Law
106. International Council of Scientific Unions
107. International Education Resource and Innovation Centre*
108. International Federation of Chemical, Energy, Mine and General Workers' Unions
109. International Federation of Industrial Energy Consumers
110. International Gas Union
111. International Institute for Energy Conservation
112. International Lake Environment Committee Foundation*
113. International Network for Environmental Management
114. International NGO Forum for Ozone Layer Protection and Against Global Warming*
115. International Organization for Standardization
116. International Organization of Motor Vehicle Manufacturers
117. International Petroleum Industry Environmental Conservation Association
118. International Society of Doctors for the Environment
119. International Society on Optics Within Life Sciences
120. International Solar Car Federation
121. International Union of Producers and Distributors of Electrical Energy
122. International Union of Public Transport
123. International Women's Year Liaison Group*
124. International Youth and Student Movement for the United Nations
125. Interstate Natural Gas Association of America
126. IWMC World Conservation Trust
127. Japan Association of Environment Assessment*
128. Japan Atomic Industrial Forum Inc*
129. Japan Automobile Federation*
130. Japan Bicycle Promotion Institute*
131. Japan Center of International and Comparative Environmental Law*
132. Japan Environment Association*
133. Japan Environment Corporation*
134. Japan Environmental Technology Association*
135. Japan Federation of Bar Associations
136. Japan Federation of Economic Organizations (Keidanren)
137. Japan Flon Gas Association
138. Japan Industrial Conference for Ozone Layer Protection
139. Japan International Forestry Promotion and Cooperation Center*
140. Japan Save the Ozone Network Gunma*
141. JICHIRO (All Japan Prefectural and Municipal Workers Union)*
142. Kiko Forum '97*
143. Kitakyushu International Techno-Cooperative Association*
144. Korea Institute of Science & Technology Europe
145. Kyoto Junior Chamber Inc*

146. Kyoto University*
147. Lancaster University
148. Loss Prevention Council
149. Midwest Research Institute/National Renewable Energy Laboratory
150. National Association of Regulatory Utility Commissioners
151. National Association of State Fire Marshals
152. National Mining Association
153. National Wildlife Federation
154. Natural Resource Users' Group
155. Natural Resources Defense Council
156. Nature Conservation Society of Japan*
157. Netherlands Economic Institute
158. New Energy and Industrial Technology Development Organization
159. Nippon International Cooperation for Community Development*
160. Nord-Sud-Forum e.V./Global Cooperation Council
161. Northwest Pacific Area Environmental Cooperation Center*
162. Nuclear Energy Institute
163. OISCA-International, Tokyo
164. Öko-Institut (Institute for Applied Ecology)
165. Overseas Evaluation Cooperation Centre**
166. Ozone Action
167. Peoples' Forum 2001, Japan
168. Potsdam Institute for Climate Impact Research
169. Railway Technical Reseach Institute*
170. RainForest ReGeneration Institute
171. Real Link Kyoto
172. Redefining Progress
173. Research Centre on Global Warming of the Japan Development Bank*
174. Research Institute of Innovative Technology for the Earth*
175. Réseau Action Climat France
176. Resources for the Future
177. SAEI (SFC Alternative Energy Innovators)*
178. Saitama Forum for Environmental Education*
179. Save the Earth! Action 97*
180. Scientists for Global Responsibilty
181. Sierra Club of Canada
182. Society of Electric Vehicle*
183. Solar Electric Light Fund
184. Solar Net*
185. SOROPTIMIST International of the Americas Inc. of the Higashi Region*
186. Southern Research Institute
187. Sovereignty International
188. Stockholm Environment Institute
189. Tata Energy Research Institute

190. Tellus Institute
191. Thailand Environment Institute
192. The Aozora Foundation*
193. The Business Council for Sustainable Energy
194. The Business Roundtable
195. The Climate Council
196. The David Suzuki Foundation
197. The Energy Conservation Center, Tokyo
198. The European Association for the Promotion of Cogeneration
199. The Federation of Electric Power Companies
200. The Forum of Local Government Representatives for Contemplation on the Environment and Industry*
201. The Fridtjof Nansen Institute
202. The Global Environmental Forum*
203. The Institute for Global Environmental Strategies*
204. The Institute of Energy Economics*
205. The Japan Economic Research Institute*
206. The Japan Electrical Manufacturers' Association
207. The Japan Environmental Education Forum*
208. The Japan Gas Association*
209. The Japan Network for Earth Environment and Prevention Pollution*
210. The Japan Scientist Association*
211. The Korea Chamber of Commerce and Industry
212. The Local Grassroots Network of Citizens*
213. The Nature Conservancy
214. The Netherlands Energy Research Foundation
215. The Pacific Rim Consortium for Energy Combustion and the Environment
216. The Pollution Related Health Damage Compensation and Prevention Association*
217. The Rockefeller Foundation
218. The Royal Institute of International Affairs
219. The Solar Century
220. The Swiss Federal Institute for Environmental Science and Technology/Human Ecology Group
221. The Uranium Institute
222. The Woods Hole Research Center
223. Union of Concerned Scientists
224. Union of Industrial and Employers' Confederations of Europe
225. United Methodist Church/General Board of Church and Society
226. United Mine Workers of America
227. United Nations Environment Development - UK Committee
228. United Nations Student Association of Japan*
229. University of Kassel
230. University of Oslo
231. University of Utrecht - Faculty of Chemistry

232. US Climate Action Network
233. Verification Technology Information Centre
234. Wild Bird Society of Japan*
235. World Business Council for Sustainable Development
236. World Coal Institute
237. World Conference on Religion and Peace
238. World Council of Churches
239. World Energy Council
240. World Resources Institute
241. World Watch Institute
242. Wuppertal Institute for Climate, Environment and Energy
243. WWF-International

Annex III

List of documents before the Conference of the Parties at its third session

FCCC/CP/1996/2	Adoption of the rules of procedure
FCCC/CP/1997/1 and Add.1-2	Provisional agenda and annotations, including suggestions for the organization of work
FCCC/CP/1997/2 and Add.1	Adoption of a protocol or another legal instrument: Fulfilment of the Berlin Mandate. Revised text under negotiation
FCCC/CP/1997/3	Financial mechanism: report of the Global Environment Facility to the Conference of the Parties at its third session
FCCC/CP/1997/4	Admission of observers: intergovernmental and non-governmental organizations
FCCC/CP/1997/5	Adoption of the rules of procedure: note by Mr. Chen Chimutengwende (Zimbabwe), President of the Conference of the Parties at its second session, on his informal consultations on the draft rules of procedure
FCCC/CP/1997/6	Credentials of the representatives of Parties to the third session of the Conference of the Parties to the United Nations Framework Convention on Climate Change: report of the Bureau
FCCC/CP/1997/INF.1	Administrative and financial matters: Programme budget of the Convention for the biennium 1998-1999. Detailed subprogramme activities and resource requirements
FCCC/CP/1997/INF.2	Status of ratification of the United Nations Framework Convention on Climate Change
FCCC/CP/1997/INF.3	Secretariat activities relating to technical and financial support to Parties
FCCC/CP/1997/INF.4	Report on the status of contributions to the core budget for the biennium 1996-1997
FCCC/CP/1997/INF.5	List of participants

FCCC/CP/1997/MISC.2	Provisional list of participants
FCCC/CP/1997/MISC.3	Review of information and possible decisions under Article 4.2 (f): submission by Turkey
FCCC/CP/1997/CRP.5	Report of the round table on transfer of technology and know-how
FCCC/CP/1997/L.1	High-level segment attended by ministers and other heads of delegation: draft list of items proposed by the Group of 77 and China
FCCC/CP/1997/L.2	Date and venue of the fourth session of the Conference of the Parties: draft decision submitted by the President
FCCC/CP/1997/L.3 and Add.1	Review of information and possible decisions under Article 4.2(f): draft decision proposed by Mr. Luis Herrera Marcano (Venezuela), Vice-President of the Conference
FCCC/CP/1997/L.4	Draft report of the Conference of the Parties on its third session
FCCC/CP/1997/L.5	Methodological issues related to a protocol or another legal instrument: draft decision sumitted by the Commitee of the Whole
FCCC/CP/1997/L.6	Expression of gratitude to the Government and the people of Japan: draft resolution submitted by Bhutan
FCCC/CP/1997/L.7	Adoption of the Kyoto Protocol to the United Nations Framework Convention on Climate Change: draft decision submitted by the Committee of the Whole
FCCC/CP/1997/L.7/Add.1	Kyoto Protocol to the United Nations Framework Convention on Climate Change
FCCC/CP/1997/L.8	Programme budget for the biennium 1998-1999: draft decision submitted by the Chairman of the SBI
FCCC/CP/1997/L.9	Implementation of Article 4 8 of the Convention: draft decision submitted by the Committee of the Whole
FCCC/SB/1997/1	Progress report on technology and technology transfer
FCCC/SB/1997/3	Development and transfer of technologies: Progress report

FCCC/SB/1997/4	Development and transfer of technologies: Update to progress report
FCCC/SBSTA/1996/20	Report of the Subsidiary Body for Scientific and Technological Advice on the work of its fourth session, Geneva, 16-18 December 1996
FCCC/SBSTA/1997/4	Report of the Subsidiary Body for Scientific and Technological Advice on the work of its fifth session, Bonn, 25-28 February 1997
FCCC/SBSTA/1997/6	Report of the Subsidiary Body for Scientific and Technological Advice on the work of its sixth session, Bonn, 28 July - 5 August 1 1997
FCCC/SBSTA/1997/10	Development and transfer of technologies: Progress report
FCCC/SBSTA/1997/12 and Corr.1-2, and Add.1	Activities implemented jointly under the pilot phase: Synthesis report on activities implemented jointly
FCCC/SBSTA/1997/14	Report of the Subsidiary Body for Scientific and Technological Advice on the work of its seventh session, Bonn, 20-28 October 1997
FCCC/SBSTA/1997/INF.3	Activities implemented jointly under the pilot phase: Contact and activity information
FCCC/SBI/1996/14	Report of the Subsidiary Body for Implementation on the work of its fourth session, Geneva, 10-11 December 1996
FCCC/SBI/1997/6	Report of the Subsidiary Body for Implementation on the work of its fifth session, Bonn, 25 February - 7 March 1997
FCCC/SBI/1997/10	Proposed programme budget of the Convention for the biennium 1998-1999
FCCC/SBI/1997/12	Volume of documentation
FCCC/SBI/1997/15	Amendments to the Convention or its Annexes
FCCC/SBI/1997/16	Report of the Subsidiary Body for Implementation on the work of its sixth session, Bonn, 28 July - 5 August 1997

FCCC/SBI/1997/18	Financial performance of UNFCCC: Contributions and expenditures in 1996-1997, and forecast for the biennium 1996-1997
FCCC/SBI/1997/21	Report of the Subsidiary Body for Implementation on the work of its seventh session, Bonn, 20-29 October 1997
FCCC/AGBM/1996/8	Report of the Ad Hoc Group on the Berlin Mandate on the work of its fourth session, Geneva, 11-16 July 1996
FCCC/AGBM/1996/11	Report of the Ad Hoc Group on the Berlin Mandate on the work of its fifth session, Geneva, 9-12 December 1996
FCCC/AGBM/1997/3 and Add.1 an Corr.1	Report of the Ad Hoc Group on the Berlin Mandate on the work of its sixth session, Bonn, 3-7 March 1997
FCCC/AGBM/1997/5	Report of the Ad Hoc Group on the Berlin Mandate on the work of its seventh session, Bonn, 31 July - 7 August 1997
FCCC/AGBM/1997/8	Report of the Ad Hoc Group on the Berlin Mandate on the work of the first part of its eighth session, Bonn, 22-31 October 1997
FCCC/AGBM/1997/8/Add.1	Report of the Ad Hoc Group on the Berlin Mandate on the work of the second part of its eighth session, Kyoto, 30 November 1997
FCCC/AG13/1996/4	Report of the Ad Hoc Group on Article 13 on the work of its third session, Geneva, 16-18 December 1996
FCCC/AG13/1997/2	Report of the Ad Hoc Group on Article 13 on the work of its fourth session, Bonn, 25-28 February 1997
FCCC/AG13/1997/4	Report of the Ad Hoc Group on Article 13 on the work of its fifth session, Bonn, 28-30 July 1997

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UNITED
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Framework Convention
on Climate Change

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CONFERENCE OF THE PARTIES

REPORT OF THE CONFERENCE OF THE PARTIES ON ITS THIRD SESSION, HELD AT KYOTO FROM 1 TO 11 DECEMBER 1997

Corrigendum

Page 17, section J. Attendance, paragraph 40

Line 2: for 158 read 159

After Niger insert Nigeria

II. RESOLUTION ADOPTED BY THE CONFERENCE OF THE PARTIES

Resolution

Page

III. OTHER ACTION TAKEN BY THE CONFERENCE OF THE PARTIES

I. DECISIONS ADOPTED BY THE CONFERENCE OF THE PARTIES

Decision 1/CP.3

Adoption of the Kyoto Protocol to the United Nations Framework Convention on Climate Change

The Conference of the Parties,

Having reviewed Article 4, paragraph 2(a) and (b), of the United Nations Framework Convention on Climate Change at its first session and having concluded that these subparagraphs are not adequate,

Recalling its decision 1/CP.1 entitled "The Berlin Mandate: Review of the adequacy of Article 4, paragraph 2(a) and (b), of the Convention, including proposals related to a protocol and decisions on follow-up", by which it agreed to begin a process to enable it to take appropriate action for the period beyond 2000 through the adoption of a protocol or another legal instrument at its third session,

Recalling further that one aim of the process was to strengthen the commitments in Article 4, paragraph 2(a) and (b) of the Convention, for developed country/other Parties included in Annex I, both to elaborate policies and measures, and to set quantified limitation and reduction objectives within specified time-frames, such as 2005, 2010 and 2020, for their anthropogenic emissions by sources and removals by sinks of greenhouse gases not controlled by the Montreal Protocol,

Recalling also that, according to the Berlin Mandate, the process will not introduce any new commitments for Parties not included in Annex I, but reaffirm existing commitments in Article 4, paragraph 1, and continue to advance the implementation of these commitments in order to achieve sustainable development, taking into account Article 4, paragraphs 3, 5 and 7,

Noting the reports of the Ad Hoc Group on the Berlin Mandate on its eight sessions,[1]

Having considered with appreciation the report presented by the Chairman of the Ad Hoc Group on the Berlin Mandate,

Taking note with appreciation of the report of the Chairman of the Committee of the Whole on the outcome of the work of the Committee,

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[1] FCCC/AGBM/1995/2 and Corr.1, and 7 and Corr.1; FCCC/AGBM/1996/5, 8, and 11; FCCC/AGBM/1997/3, 3/Add.1 and Corr 1, 5, 8 and 8/Add.1.

Recognizing the need to prepare for the early entry into force of the Kyoto Protocol to the United Nations Framework Convention on Climate Change,

Aware of the desirability of the timely commencement of work to pave the way for a successful outcome of the fourth session of the Conference of the Parties, to be held in Buenos Aires, Argentina,

1. *Decides to adopt* the Kyoto Protocol to the United Nations Framework Convention on Climate Change, annexed hereto;

2. *Requests* the Secretary-General of the United Nations to be the Depositary of this Protocol and to open it for signature in New York from 16 March 1998 until 15 March 1999;

3. *Invites* all Parties to the United Nations Framework Convention on Climate Change to sign the Protocol on 16 March 1998 or at the earliest opportunity thereafter, and to deposit instruments of ratification, acceptance or approval, or instruments of accession where appropriate, as soon as possible;

4. *Further invites* States that are not parties to the Convention to ratify or accede to it, as appropriate, without delay, so that they may become Parties to the Protocol;

5. *Requests* the Chairman of the Subsidiary Body for Scientific and Technological Advice and the Chairman of the Subsidiary Body for Implementation, taking into account the approved programme budget for the biennium 1998-1999 and the related programme of work of the secretariat,[2] to give guidance to the secretariat on the preparatory work needed for consideration by the Conference of the Parties, at its fourth session, of the following matters, and to allocate work thereon to the respective subsidiary bodies as appropriate:

(a) Determination of modalities, rules and guidelines as to how, and which, additional human-induced activities related to changes in greenhouse gas emissions by sources and removals by sinks in the agricultural soils and the land-use change and forestry categories shall be added to, or subtracted from, the assigned amounts for Parties to the Protocol included in Annex I to the Convention, as provided for under Article 3, paragraph 4, of the Protocol;

(b) Definition of relevant principles, modalities, rules and guidelines, in particular for verification, reporting and accountability of emissions trading, pursuant to Article 17 of the Protocol;

(c) Elaboration of guidelines for any Party to the Protocol included in Annex I to the Convention to transfer to, or acquire from, any other such Party emission reduction units resulting from projects aimed at reducing anthropogenic emissions by sources or enhancing

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[2] FCCC/CP/1997/INF.1.

anthropogenic removals by sinks of greenhouse gases in any sector of the economy, as provided for under Article 6 of the Protocol;

(d) Consideration of and, as appropriate, action on suitable methodologies to address the situation of Parties listed in Annex B to the Protocol for which single projects would have a significant proportional impact on emissions in the commitment period;

(e) Analysis of the implications of Article 12, paragraph 10, of the Protocol;

6. *Invites* the Chairman of the Subsidiary Body for Scientific and Technological Advice and the Chairman of the Subsidiary Body for Implementation to make a joint proposal to those bodies, at their eighth sessions, on the allocation to them of preparatory work to enable the Conference of the Parties serving as the meeting of the Parties to the Protocol, at its first session after the entry into force of the Protocol, to accomplish the tasks assigned to it by the Protocol.

12th plenary meeting
11 December 1997

Annex

KYOTO PROTOCOL TO THE UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE

The Parties to this Protocol,

Being Parties to the United Nations Framework Convention on Climate Change, hereinafter referred to as "the Convention",

In pursuit of the ultimate objective of the Convention as stated in its Article 2,

Recalling the provisions of the Convention,

Being guided by Article 3 of the Convention,

Pursuant to the Berlin Mandate adopted by decision 1/CP.1 of the Conference of the Parties to the Convention at its first session,

Have agreed as follows:

Article 1

For the purposes of this Protocol, the definitions contained in Article 1 of the Convention shall apply. In addition:

1. "Conference of the Parties" means the Conference of the Parties to the Convention.

2. "Convention" means the United Nations Framework Convention on Climate Change, adopted in New York on 9 May 1992.

3. "Intergovernmental Panel on Climate Change" means the Intergovernmental Panel on Climate Change established in 1988 jointly by the World Meteorological Organization and the United Nations Environment Programme.

4. "Montreal Protocol" means the Montreal Protocol on Substances that Deplete the Ozone Layer, adopted in Montreal on 16 September 1987 and as subsequently adjusted and amended.

5. "Parties present and voting" means Parties present and casting an affirmative or negative vote

6. "Party" means, unless the context otherwise indicates, a Party to this Protocol.

7. "Party included in Annex I" means a Party included in Annex I to the Convention, as may be amended, or a Party which has made a notification under Article 4, paragraph 2(g), of the Convention.

Article 2

1. Each Party included in Annex I, in achieving its quantified emission limitation and reduction commitments under Article 3, in order to promote sustainable development, shall:

(a) Implement and/or further elaborate policies and measures in accordance with its national circumstances, such as:

(i) Enhancement of energy efficiency in relevant sectors of the national economy;

(ii) Protection and enhancement of sinks and reservoirs of greenhouse gases not controlled by the Montreal Protocol, taking into account its commitments under relevant international environmental agreements; promotion of sustainable forest management practices, afforestation and reforestation;

(iii) Promotion of sustainable forms of agriculture in light of climate change considerations;

(iv) Research on, and promotion, development and increased use of, new and renewable forms of energy, of carbon dioxide sequestration technologies and of advanced and innovative environmentally sound technologies;

(v) Progressive reduction or phasing out of market imperfections, fiscal incentives, tax and duty exemptions and subsidies in all greenhouse gas emitting sectors that run counter to the objective of the Convention and application of market instruments;

(vi) Encouragement of appropriate reforms in relevant sectors aimed at promoting policies and measures which limit or reduce emissions of greenhouse gases not controlled by the Montreal Protocol;

(vii) Measures to limit and/or reduce emissions of greenhouse gases not controlled by the Montreal Protocol in the transport sector;

(viii) Limitation and/or reduction of methane emissions through recovery and use in waste management, as well as in the production, transport and distribution of energy;

(b) Cooperate with other such Parties to enhance the individual and combined effectiveness of their policies and measures adopted under this Article, pursuant to Article 4, paragraph 2(e)(i), of the Convention. To this end, these Parties shall take steps to share their experience and exchange information on such policies and measures, including developing ways of improving their comparability, transparency and effectiveness. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall, at its first session or as soon as practicable thereafter, consider ways to facilitate such cooperation, taking into account all relevant information.

2. The Parties included in Annex I shall pursue limitation or reduction of emissions of greenhouse gases not controlled by the Montreal Protocol from aviation and marine bunker fuels, working through the International Civil Aviation Organization and the International Maritime Organization, respectively.

3. The Parties included in Annex I shall strive to implement policies and measures under this Article in such a way as to minimize adverse effects, including the adverse effects of climate change, effects on international trade, and social, environmental and economic impacts on other Parties, especially developing country Parties and in particular those identified in Article 4, paragraphs 8 and 9, of the Convention, taking into account Article 3 of the Convention. The Conference of the Parties serving as the meeting of the Parties to this Protocol may take further action, as appropriate, to promote the implementation of the provisions of this paragraph.

4. The Conference of the Parties serving as the meeting of the Parties to this Protocol, if it decides that it would be beneficial to coordinate any of the policies and measures in paragraph 1(a) above, taking into account different national circumstances and potential effects, shall consider ways and means to elaborate the coordination of such policies and measures.

Article 3

1. The Parties included in Annex I shall, individually or jointly, ensure that their aggregate anthropogenic carbon dioxide equivalent emissions of the greenhouse gases listed in Annex A do not exceed their assigned amounts, calculated pursuant to their quantified emission limitation and reduction commitments inscribed in Annex B and in accordance with the provisions of this Article, with a view to reducing their overall emissions of such gases by at least 5 per cent below 1990 levels in the commitment period 2008 to 2012.

2. Each Party included in Annex I shall, by 2005, have made demonstrable progress in achieving its commitments under this Protocol.

3. The net changes in greenhouse gas emissions by sources and removals by sinks resulting from direct human-induced land-use change and forestry activities, limited to afforestation, reforestation and deforestation since 1990, measured as verifiable changes in carbon stocks in each commitment period, shall be used to meet the commitments under this Article of each Party included in Annex I. The greenhouse gas emissions by sources and removals by sinks associated with those activities shall be reported in a transparent and verifiable manner and reviewed in accordance with Articles 7 and 8.

4. Prior to the first session of the Conference of the Parties serving as the meeting of the Parties to this Protocol, each Party included in Annex I shall provide, for consideration by the Subsidiary Body for Scientific and Technological Advice, data to establish its level of carbon stocks in 1990 and to enable an estimate to be made of its changes in carbon stocks in subsequent years. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall, at its first session or as soon as practicable thereafter, decide upon modalities, rules and guidelines as to how, and which, additional human-induced activities related to changes in greenhouse gas emissions by sources and removals by sinks in the agricultural soils and the land-use change and forestry categories shall be added to, or subtracted from, the assigned amounts for Parties included in Annex I, taking into account uncertainties, transparency in reporting, verifiability, the methodological work of the Intergovernmental Panel on Climate Change, the advice provided by the Subsidiary Body for Scientific and Technological Advice in accordance with Article 5 and the decisions of the Conference of the Parties. Such a decision shall apply in the second and subsequent commitment periods. A Party may choose to apply such a decision on these additional human-induced activities for its first commitment period, provided that these activities have taken place since 1990.

5. The Parties included in Annex I undergoing the process of transition to a market economy whose base year or period was established pursuant to decision 9/CP.2 of the Conference of the Parties at its second session shall use that base year or period for the implementation of their commitments under this Article. Any other Party included in Annex I undergoing the process of transition to a market economy which has not yet submitted its first national communication under Article 12 of the Convention may also notify the Conference of the Parties serving as the meeting of the Parties to this Protocol that it intends to use an historical base year or period other than 1990 for the implementation of its commitments under this Article. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall decide on the acceptance of such notification.

6. Taking into account Article 4, paragraph 6, of the Convention, in the implementation of their commitments under this Protocol other than those under this Article, a certain degree of flexibility shall be allowed by the Conference of the Parties serving as the meeting of the Parties to this Protocol to the Parties included in Annex I undergoing the process of transition to a market economy.

7. In the first quantified emission limitation and reduction commitment period, from 2008 to 2012, the assigned amount for each Party included in Annex I shall be equal to the percentage inscribed for it in Annex B of its aggregate anthropogenic carbon dioxide equivalent emissions of the greenhouse gases listed in Annex A in 1990, or the base year or period determined in accordance with paragraph 5 above, multiplied by five. Those Parties included in Annex I for whom land-use change and forestry constituted a net source of greenhouse gas emissions in 1990 shall include in their 1990 emissions base year or period the aggregate anthropogenic carbon dioxide equivalent emissions by sources minus removals by sinks in 1990 from land-use change for the purposes of calculating their assigned amount.

8. Any Party included in Annex I may use 1995 as its base year for hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride, for the purposes of the calculation referred to in paragraph 7 above.

9. Commitments for subsequent periods for Parties included in Annex I shall be established in amendments to Annex B to this Protocol, which shall be adopted in accordance with the provisions of Article 21, paragraph 7. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall initiate the consideration of such commitments at least seven years before the end of the first commitment period referred to in paragraph 1 above.

10. Any emission reduction units, or any part of an assigned amount, which a Party acquires from another Party in accordance with the provisions of Article 6 or of Article 17 shall be added to the assigned amount for the acquiring Party.

11. Any emission reduction units, or any part of an assigned amount, which a Party transfers to another Party in accordance with the provisions of Article 6 or of Article 17 shall be subtracted from the assigned amount for the transferring Party.

12. Any certified emission reductions which a Party acquires from another Party in accordance with the provisions of Article 12 shall be added to the assigned amount for the acquiring Party.

13. If the emissions of a Party included in Annex I in a commitment period are less than its assigned amount under this Article, this difference shall, on request of that Party, be added to the assigned amount for that Party for subsequent commitment periods.

14. Each Party included in Annex I shall strive to implement the commitments mentioned in paragraph 1 above in such a way as to minimize adverse social, environmental and economic impacts on developing country Parties, particularly those identified in Article 4, paragraphs 8 and 9, of the Convention. In line with relevant decisions of the Conference of the Parties on the implementation of those paragraphs, the Conference of the Parties serving as the meeting of the Parties to this Protocol shall, at its first session, consider what actions are necessary to minimize the adverse effects of climate change and/or the impacts of response measures on Parties referred

to in those paragraphs. Among the issues to be considered shall be the establishment of funding, insurance and transfer of technology.

Article 4

1. Any Parties included in Annex I that have reached an agreement to fulfil their commitments under Article 3 jointly, shall be deemed to have met those commitments provided that their total combined aggregate anthropogenic carbon dioxide equivalent emissions of the greenhouse gases listed in Annex A do not exceed their assigned amounts calculated pursuant to their quantified emission limitation and reduction commitments inscribed in Annex B and in accordance with the provisions of Article 3. The respective emission level allocated to each of the Parties to the agreement shall be set out in that agreement.

2. The Parties to any such agreement shall notify the secretariat of the terms of the agreement on the date of deposit of their instruments of ratification, acceptance or approval of this Protocol, or accession thereto. The secretariat shall in turn inform the Parties and signatories to the Convention of the terms of the agreement.

3. Any such agreement shall remain in operation for the duration of the commitment period specified in Article 3, paragraph 7.

4. If Parties acting jointly do so in the framework of, and together with, a regional economic integration organization, any alteration in the composition of the organization after adoption of this Protocol shall not affect existing commitments under this Protocol. Any alteration in the composition of the organization shall only apply for the purposes of those commitments under Article 3 that are adopted subsequent to that alteration.

5. In the event of failure by the Parties to such an agreement to achieve their total combined level of emission reductions, each Party to that agreement shall be responsible for its own level of emissions set out in the agreement.

6. If Parties acting jointly do so in the framework of, and together with, a regional economic integration organization which is itself a Party to this Protocol, each member State of that regional economic integration organization individually, and together with the regional economic integration organization acting in accordance with Article 24, shall, in the event of failure to achieve the total combined level of emission reductions, be responsible for its level of emissions as notified in accordance with this Article.

Article 5

1. Each Party included in Annex I shall have in place, no later than one year prior to the start of the first commitment period, a national system for the estimation of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol. Guidelines for such national systems, which shall incorporate the

methodologies specified in paragraph 2 below, shall be decided upon by the Conference of the Parties serving as the meeting of the Parties to this Protocol at its first session.

2. Methodologies for estimating anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol shall be those accepted by the Intergovernmental Panel on Climate Change and agreed upon by the Conference of the Parties at its third session. Where such methodologies are not used, appropriate adjustments shall be applied according to methodologies agreed upon by the Conference of the Parties serving as the meeting of the Parties to this Protocol at its first session. Based on the work of, *inter alia*, the Intergovernmental Panel on Climate Change and advice provided by the Subsidiary Body for Scientific and Technological Advice, the Conference of the Parties serving as the meeting of the Parties to this Protocol shall regularly review and, as appropriate, revise such methodologies and adjustments, taking fully into account any relevant decisions by the Conference of the Parties. Any revision to methodologies or adjustments shall be used only for the purposes of ascertaining compliance with commitments under Article 3 in respect of any commitment period adopted subsequent to that revision.

3. The global warming potentials used to calculate the carbon dioxide equivalence of anthropogenic emissions by sources and removals by sinks of greenhouse gases listed in Annex A shall be those accepted by the Intergovernmental Panel on Climate Change and agreed upon by the Conference of the Parties at its third session. Based on the work of, *inter alia*, the Intergovernmental Panel on Climate Change and advice provided by the Subsidiary Body for Scientific and Technological Advice, the Conference of the Parties serving as the meeting of the Parties to this Protocol shall regularly review and, as appropriate, revise the global warming potential of each such greenhouse gas, taking fully into account any relevant decisions by the Conference of the Parties. Any revision to a global warming potential shall apply only to commitments under Article 3 in respect of any commitment period adopted subsequent to that revision.

Article 6

1. For the purpose of meeting its commitments under Article 3, any Party included in Annex I may transfer to, or acquire from, any other such Party emission reduction units resulting from projects aimed at reducing anthropogenic emissions by sources or enhancing anthropogenic removals by sinks of greenhouse gases in any sector of the economy, provided that:

(a) Any such project has the approval of the Parties involved,

(b) Any such project provides a reduction in emissions by sources, or an enhancement of removals by sinks, that is additional to any that would otherwise occur;

(c) It does not acquire any emission reduction units if it is not in compliance with its obligations under Articles 5 and 7; and

(d) The acquisition of emission reduction units shall be supplemental to domestic actions for the purposes of meeting commitments under Article 3.

2. The Conference of the Parties serving as the meeting of the Parties to this Protocol may, at its first session or as soon as practicable thereafter, further elaborate guidelines for the implementation of this Article, including for verification and reporting.

3. A Party included in Annex I may authorize legal entities to participate, under its responsibility, in actions leading to the generation, transfer or acquisition under this Article of emission reduction units.

4. If a question of implementation by a Party included in Annex I of the requirements referred to in this Article is identified in accordance with the relevant provisions of Article 8, transfers and acquisitions of emission reduction units may continue to be made after the question has been identified, provided that any such units may not be used by a Party to meet its commitments under Article 3 until any issue of compliance is resolved.

Article 7

1. Each Party included in Annex I shall incorporate in its annual inventory of anthropogenic emissions by sources and removals by sinks of greenhouse gases not controlled by the Montreal Protocol, submitted in accordance with the relevant decisions of the Conference of the Parties, the necessary supplementary information for the purposes of ensuring compliance with Article 3, to be determined in accordance with paragraph 4 below.

2. Each Party included in Annex I shall incorporate in its national communication, submitted under Article 12 of the Convention, the supplementary information necessary to demonstrate compliance with its commitments under this Protocol, to be determined in accordance with paragraph 4 below.

3. Each Party included in Annex I shall submit the information required under paragraph 1 above annually, beginning with the first inventory due under the Convention for the first year of the commitment period after this Protocol has entered into force for that Party. Each such Party shall submit the information required under paragraph 2 above as part of the first national communication due under the Convention after this Protocol has entered into force for it and after the adoption of guidelines as provided for in paragraph 4 below. The frequency of subsequent submission of information required under this Article shall be determined by the Conference of the Parties serving as the meeting of the Parties to this Protocol, taking into account any timetable for the submission of national communications decided upon by the Conference of the Parties.

4. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall adopt at its first session, and review periodically thereafter, guidelines for the preparation of the information required under this Article, taking into account guidelines for the preparation of

national communications by Parties included in Annex I adopted by the Conference of the Parties. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall also, prior to the first commitment period, decide upon modalities for the accounting of assigned amounts.

Article 8

1. The information submitted under Article 7 by each Party included in Annex I shall be reviewed by expert review teams pursuant to the relevant decisions of the Conference of the Parties and in accordance with guidelines adopted for this purpose by the Conference of the Parties serving as the meeting of the Parties to this Protocol under paragraph 4 below. The information submitted under Article 7, paragraph 1, by each Party included in Annex I shall be reviewed as part of the annual compilation and accounting of emissions inventories and assigned amounts. Additionally, the information submitted under Article 7, paragraph 2, by each Party included in Annex I shall be reviewed as part of the review of communications.

2. Expert review teams shall be coordinated by the secretariat and shall be composed of experts selected from those nominated by Parties to the Convention and, as appropriate, by intergovernmental organizations, in accordance with guidance provided for this purpose by the Conference of the Parties.

3. The review process shall provide a thorough and comprehensive technical assessment of all aspects of the implementation by a Party of this Protocol. The expert review teams shall prepare a report to the Conference of the Parties serving as the meeting of the Parties to this Protocol, assessing the implementation of the commitments of the Party and identifying any potential problems in, and factors influencing, the fulfilment of commitments. Such reports shall be circulated by the secretariat to all Parties to the Convention. The secretariat shall list those questions of implementation indicated in such reports for further consideration by the Conference of the Parties serving as the meeting of the Parties to this Protocol.

4. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall adopt at its first session, and review periodically thereafter, guidelines for the review of implementation of this Protocol by expert review teams taking into account the relevant decisions of the Conference of the Parties.

5. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall, with the assistance of the Subsidiary Body for Implementation and, as appropriate, the Subsidiary Body for Scientific and Technological Advice, consider:

(a) The information submitted by Parties under Article 7 and the reports of the expert reviews thereon conducted under this Article; and

(b) Those questions of implementation listed by the secretariat under paragraph 3 above, as well as any questions raised by Parties.

6. Pursuant to its consideration of the information referred to in paragraph 5 above, the Conference of the Parties serving as the meeting of the Parties to this Protocol shall take decisions on any matter required for the implementation of this Protocol.

Article 9

1. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall periodically review this Protocol in the light of the best available scientific information and assessments on climate change and its impacts, as well as relevant technical, social and economic information. Such reviews shall be coordinated with pertinent reviews under the Convention, in particular those required by Article 4, paragraph 2(d), and Article 7, paragraph 2(a), of the Convention. Based on these reviews, the Conference of the Parties serving as the meeting of the Parties to this Protocol shall take appropriate action.

2. The first review shall take place at the second session of the Conference of the Parties serving as the meeting of the Parties to this Protocol. Further reviews shall take place at regular intervals and in a timely manner.

Article 10

All Parties, taking into account their common but differentiated responsibilities and their specific national and regional development priorities, objectives and circumstances, without introducing any new commitments for Parties not included in Annex I, but reaffirming existing commitments under Article 4, paragraph 1, of the Convention, and continuing to advance the implementation of these commitments in order to achieve sustainable development, taking into account Article 4, paragraphs 3. 5 and 7, of the Convention, shall:

(a) Formulate, where relevant and to the extent possible, cost-effective national and, where appropriate, regional programmes to improve the quality of local emission factors, activity data and/or models which reflect the socio-economic conditions of each Party for the preparation and periodic updating of national inventories of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol, using comparable methodologies to be agreed upon by the Conference of the Parties, and consistent with the guidelines for the preparation of national communications adopted by the Conference of the Parties;

(b) Formulate, implement, publish and regularly update national and, where appropriate, regional programmes containing measures to mitigate climate change and measures to facilitate adequate adaptation to climate change:

(i) Such programmes would, *inter alia*, concern the energy, transport and industry sectors as well as agriculture, forestry and waste management. Furthermore, adaptation technologies and methods for improving spatial planning would improve adaptation to climate change; and

(ii) Parties included in Annex I shall submit information on action under this Protocol, including national programmes, in accordance with Article 7; and other Parties shall seek to include in their national communications, as appropriate, information on programmes which contain measures that the Party believes contribute to addressing climate change and its adverse impacts, including the abatement of increases in greenhouse gas emissions, and enhancement of and removals by sinks, capacity building and adaptation measures;

(c) Cooperate in the promotion of effective modalities for the development, application and diffusion of, and take all practicable steps to promote, facilitate and finance, as appropriate, the transfer of, or access to, environmentally sound technologies, know-how, practices and processes pertinent to climate change, in particular to developing countries, including the formulation of policies and programmes for the effective transfer of environmentally sound technologies that are publicly owned or in the public domain and the creation of an enabling environment for the private sector, to promote and enhance the transfer of, and access to, environmentally sound technologies;

(d) Cooperate in scientific and technical research and promote the maintenance and the development of systematic observation systems and development of data archives to reduce uncertainties related to the climate system, the adverse impacts of climate change and the economic and social consequences of various response strategies, and promote the development and strengthening of endogenous capacities and capabilities to participate in international and intergovernmental efforts, programmes and networks on research and systematic observation, taking into account Article 5 of the Convention;

(e) Cooperate in and promote at the international level, and, where appropriate, using existing bodies, the development and implementation of education and training programmes, including the strengthening of national capacity building, in particular human and institutional capacities and the exchange or secondment of personnel to train experts in this field, in particular for developing countries, and facilitate at the national level public awareness of, and public access to information on, climate change. Suitable modalities should be developed to implement these activities through the relevant bodies of the Convention, taking into account Article 6 of the Convention;

(f) Include in their national communications information on programmes and activities undertaken pursuant to this Article in accordance with relevant decisions of the Conference of the Parties; and

(g) Give full consideration, in implementing the commitments under this Article, to Article 4, paragraph 8, of the Convention.

Article 11

1. In the implementation of Article 10, Parties shall take into account the provisions of Article 4, paragraphs 4, 5, 7, 8 and 9, of the Convention.

2. In the context of the implementation of Article 4, paragraph 1, of the Convention, in accordance with the provisions of Article 4, paragraph 3, and Article 11 of the Convention, and through the entity or entities entrusted with the operation of the financial mechanism of the Convention, the developed country Parties and other developed Parties included in Annex II to the Convention shall:

(a) Provide new and additional financial resources to meet the agreed full costs incurred by developing country Parties in advancing the implementation of existing commitments under Article 4, paragraph 1(a), of the Convention that are covered in Article 10, subparagraph (a); and

(b) Also provide such financial resources, including for the transfer of technology, needed by the developing country Parties to meet the agreed full incremental costs of advancing the implementation of existing commitments under Article 4, paragraph 1, of the Convention that are covered by Article 10 and that are agreed between a developing country Party and the international entity or entities referred to in Article 11 of the Convention, in accordance with that Article.

The implementation of these existing commitments shall take into account the need for adequacy and predictability in the flow of funds and the importance of appropriate burden sharing among developed country Parties. The guidance to the entity or entities entrusted with the operation of the financial mechanism of the Convention in relevant decisions of the Conference of the Parties, including those agreed before the adoption of this Protocol, shall apply *mutatis mutandis* to the provisions of this paragraph.

3. The developed country Parties and other developed Parties in Annex II to the Convention may also provide, and developing country Parties avail themselves of, financial resources for the implementation of Article 10, through bilateral, regional and other multilateral channels.

Article 12

1. A clean development mechanism is hereby defined.

2 The purpose of the clean development mechanism shall be to assist Parties not included in Annex I in achieving sustainable development and in contributing to the ultimate objective of the Convention, and to assist Parties included in Annex I in achieving compliance with their quantified emission limitation and reduction commitments under Article 3.

3. Under the clean development mechanism:

(a) Parties not included in Annex I will benefit from project activities resulting in certified emission reductions; and

(b) Parties included in Annex I may use the certified emission reductions accruing from such project activities to contribute to compliance with part of their quantified emission limitation and reduction commitments under Article 3, as determined by the Conference of the Parties serving as the meeting of the Parties to this Protocol.

4. The clean development mechanism shall be subject to the authority and guidance of the Conference of the Parties serving as the meeting of the Parties to this Protocol and be supervised by an executive board of the clean development mechanism.

5. Emission reductions resulting from each project activity shall be certified by operational entities to be designated by the Conference of the Parties serving as the meeting of the Parties to this Protocol, on the basis of:

(a) Voluntary participation approved by each Party involved;

(b) Real, measurable, and long-term benefits related to the mitigation of climate change; and

(c) Reductions in emissions that are additional to any that would occur in the absence of the certified project activity.

6. The clean development mechanism shall assist in arranging funding of certified project activities as necessary.

7. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall, at its first session, elaborate modalities and procedures with the objective of ensuring transparency, efficiency and accountability through independent auditing and verification of project activities.

8. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall ensure that a share of the proceeds from certified project activities is used to cover administrative expenses as well as to assist developing country Parties that are particularly vulnerable to the adverse effects of climate change to meet the costs of adaptation.

9. Participation under the clean development mechanism, including in activities mentioned in paragraph 3(a) above and in the acquisition of certified emission reductions, may involve private and/or public entities, and is to be subject to whatever guidance may be provided by the executive board of the clean development mechanism.

10. Certified emission reductions obtained during the period from the year 2000 up to the beginning of the first commitment period can be used to assist in achieving compliance in the first commitment period.

Article 13

1. The Conference of the Parties, the supreme body of the Convention, shall serve as the meeting of the Parties to this Protocol.

2. Parties to the Convention that are not Parties to this Protocol may participate as observers in the proceedings of any session of the Conference of the Parties serving as the meeting of the Parties to this Protocol. When the Conference of the Parties serves as the meeting of the Parties to this Protocol, decisions under this Protocol shall be taken only by those that are Parties to this Protocol.

3. When the Conference of the Parties serves as the meeting of the Parties to this Protocol, any member of the Bureau of the Conference of the Parties representing a Party to the Convention but, at that time, not a Party to this Protocol, shall be replaced by an additional member to be elected by and from amongst the Parties to this Protocol.

4. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall keep under regular review the implementation of this Protocol and shall make, within its mandate, the decisions necessary to promote its effective implementation. It shall perform the functions assigned to it by this Protocol and shall.

(a) Assess, on the basis of all information made available to it in accordance with the provisions of this Protocol, the implementation of this Protocol by the Parties, the overall effects of the measures taken pursuant to this Protocol, in particular environmental, economic and social effects as well as their cumulative impacts and the extent to which progress towards the objective of the Convention is being achieved;

(b) Periodically examine the obligations of the Parties under this Protocol, giving due consideration to any reviews required by Article 4, paragraph 2(d), and Article 7, paragraph 2, of the Convention, in the light of the objective of the Convention, the experience gained in its implementation and the evolution of scientific and technological knowledge, and in this respect consider and adopt regular reports on the implementation of this Protocol;

(c) Promote and facilitate the exchange of information on measures adopted by the Parties to address climate change and its effects, taking into account the differing circumstances, responsibilities and capabilities of the Parties and their respective commitments under this Protocol;

(d) Facilitate, at the request of two or more Parties, the coordination of measures adopted by them to address climate change and its effects, taking into account the differing circumstances, responsibilities and capabilities of the Parties and their respective commitments under this Protocol;

(e) Promote and guide, in accordance with the objective of the Convention and the provisions of this Protocol, and taking fully into account the relevant decisions by the Conference of the Parties, the development and periodic refinement of comparable methodologies for the effective implementation of this Protocol, to be agreed on by the Conference of the Parties serving as the meeting of the Parties to this Protocol;

(f) Make recommendations on any matters necessary for the implementation of this Protocol;

(g) Seek to mobilize additional financial resources in accordance with Article 11, paragraph 2;

(h) Establish such subsidiary bodies as are deemed necessary for the implementation of this Protocol;

(i) Seek and utilize, where appropriate, the services and cooperation of, and information provided by, competent international organizations and intergovernmental and non-governmental bodies; and

(j) Exercise such other functions as may be required for the implementation of this Protocol, and consider any assignment resulting from a decision by the Conference of the Parties.

5. The rules of procedure of the Conference of the Parties and financial procedures applied under the Convention shall be applied *mutatis mutandis* under this Protocol, except as may be otherwise decided by consensus by the Conference of the Parties serving as the meeting of the Parties to this Protocol.

6. The first session of the Conference of the Parties serving as the meeting of the Parties to this Protocol shall be convened by the secretariat in conjunction with the first session of the Conference of the Parties that is scheduled after the date of the entry into force of this Protocol. Subsequent ordinary sessions of the Conference of the Parties serving as the meeting of the Parties to this Protocol shall be held every year and in conjunction with ordinary sessions of the Conference of the Parties, unless otherwise decided by the Conference of the Parties serving as the meeting of the Parties to this Protocol.

7. Extraordinary sessions of the Conference of the Parties serving as the meeting of the Parties to this Protocol shall be held at such other times as may be deemed necessary by the Conference of the Parties serving as the meeting of the Parties to this Protocol, or at the written request of any Party, provided that, within six months of the request being communicated to the Parties by the secretariat, it is supported by at least one third of the Parties.

8. The United Nations, its specialized agencies and the International Atomic Energy Agency, as well as any State member thereof or observers thereto not party to the Convention, may be represented at sessions of the Conference of the Parties serving as the meeting of the Parties to this Protocol as observers. Any body or agency, whether national or international, governmental or non-governmental, which is qualified in matters covered by this Protocol and which has informed the secretariat of its wish to be represented at a session of the Conference of the Parties serving as the meeting of the Parties to this Protocol as an observer, may be so admitted unless at least one third of the Parties present object The admission and participation of observers shall be subject to the rules of procedure, as referred to in paragraph 5 above.

Article 14

1. The secretariat established by Article 8 of the Convention shall serve as the secretariat of this Protocol.

2. Article 8, paragraph 2, of the Convention on the functions of the secretariat, and Article 8, paragraph 3, of the Convention on arrangements made for the functioning of the secretariat, shall apply *mutatis mutandis* to this Protocol. The secretariat shall, in addition, exercise the functions assigned to it under this Protocol.

Article 15

1. The Subsidiary Body for Scientific and Technological Advice and the Subsidiary Body for Implementation established by Articles 9 and 10 of the Convention shall serve as, respectively, the Subsidiary Body for Scientific and Technological Advice and the Subsidiary Body for Implementation of this Protocol. The provisions relating to the functioning of these two bodies under the Convention shall apply *mutatis mutandis* to this Protocol. Sessions of the meetings of the Subsidiary Body for Scientific and Technological Advice and the Subsidiary Body for Implementation of this Protocol shall be held in conjunction with the meetings of, respectively, the Subsidiary Body for Scientific and Technological Advice and the Subsidiary Body for Implementation of the Convention.

2. Parties to the Convention that are not Parties to this Protocol may participate as observers in the proceedings of any session of the subsidiary bodies. When the subsidiary bodies serve as the subsidiary bodies of this Protocol, decisions under this Protocol shall be taken only by those that are Parties to this Protocol.

3. When the subsidiary bodies established by Articles 9 and 10 of the Convention exercise their functions with regard to matters concerning this Protocol, any member of the Bureaux of those subsidiary bodies representing a Party to the Convention but, at that time, not a party to this Protocol, shall be replaced by an additional member to be elected by and from amongst the Parties to this Protocol.

Article 16

The Conference of the Parties serving as the meeting of the Parties to this Protocol shall, as soon as practicable, consider the application to this Protocol of, and modify as appropriate, the multilateral consultative process referred to in Article 13 of the Convention, in the light of any relevant decisions that may be taken by the Conference of the Parties. Any multilateral consultative process that may be applied to this Protocol shall operate without prejudice to the procedures and mechanisms established in accordance with Article 18.

Article 17

The Conference of the Parties shall define the relevant principles, modalities, rules and guidelines, in particular for verification, reporting and accountability for emissions trading. The Parties included in Annex B may participate in emissions trading for the purposes of fulfilling their commitments under Article 3. Any such trading shall be supplemental to domestic actions for the purpose of meeting quantified emission limitation and reduction commitments under that Article.

Article 18

The Conference of the Parties serving as the meeting of the Parties to this Protocol shall, at its first session, approve appropriate and effective procedures and mechanisms to determine and to address cases of non-compliance with the provisions of this Protocol, including through the development of an indicative list of consequences, taking into account the cause, type, degree and frequency of non-compliance. Any procedures and mechanisms under this Article entailing binding consequences shall be adopted by means of an amendment to this Protocol.

Article 19

The provisions of Article 14 of the Convention on settlement of disputes shall apply *mutatis mutandis* to this Protocol.

Article 20

1. Any Party may propose amendments to this Protocol.

2. Amendments to this Protocol shall be adopted at an ordinary session of the Conference of the Parties serving as the meeting of the Parties to this Protocol. The text of any proposed amendment to this Protocol shall be communicated to the Parties by the secretariat at least six months before the meeting at which it is proposed for adoption. The secretariat shall also communicate the text of any proposed amendments to the Parties and signatories to the Convention and, for information, to the Depositary.

3. The Parties shall make every effort to reach agreement on any proposed amendment to this Protocol by consensus. If all efforts at consensus have been exhausted, and no agreement reached, the amendment shall as a last resort be adopted by a three-fourths majority vote of the Parties present and voting at the meeting. The adopted amendment shall be communicated by the secretariat to the Depositary, who shall circulate it to all Parties for their acceptance.

4. Instruments of acceptance in respect of an amendment shall be deposited with the Depositary. An amendment adopted in accordance with paragraph 3 above shall enter into force for those Parties having accepted it on the ninetieth day after the date of receipt by the Depositary of an instrument of acceptance by at least three fourths of the Parties to this Protocol.

5. The amendment shall enter into force for any other Party on the ninetieth day after the date on which that Party deposits with the Depositary its instrument of acceptance of the said amendment.

Article 21

1. Annexes to this Protocol shall form an integral part thereof and, unless otherwise expressly provided, a reference to this Protocol constitutes at the same time a reference to any annexes thereto. Any annexes adopted after the entry into force of this Protocol shall be restricted to lists, forms and any other material of a descriptive nature that is of a scientific, technical, procedural or administrative character.

2. Any Party may make proposals for an annex to this Protocol and may propose amendments to annexes to this Protocol.

3. Annexes to this Protocol and amendments to annexes to this Protocol shall be adopted at an ordinary session of the Conference of the Parties serving as the meeting of the Parties to this Protocol. The text of any proposed annex or amendment to an annex shall be communicated to the Parties by the secretariat at least six months before the meeting at which it is proposed for adoption. The secretariat shall also communicate the text of any proposed annex or amendment to an annex to the Parties and signatories to the Convention and, for information, to the Depositary.

4. The Parties shall make every effort to reach agreement on any proposed annex or amendment to an annex by consensus. If all efforts at consensus have been exhausted, and no agreement reached, the annex or amendment to an annex shall as a last resort be adopted by a three-fourths majority vote of the Parties present and voting at the meeting. The adopted annex or amendment to an annex shall be communicated by the secretariat to the Depositary, who shall circulate it to all Parties for their acceptance.

5. An annex, or amendment to an annex other than Annex A or B, that has been adopted in accordance with paragraphs 3 and 4 above shall enter into force for all Parties to this Protocol six months after the date of the communication by the Depositary to such Parties of the adoption of

the annex or adoption of the amendment to the annex, except for those Parties that have notified the Depositary, in writing, within that period of their non-acceptance of the annex or amendment to the annex. The annex or amendment to an annex shall enter into force for Parties which withdraw their notification of non-acceptance on the ninetieth day after the date on which withdrawal of such notification has been received by the Depositary.

6. If the adoption of an annex or an amendment to an annex involves an amendment to this Protocol, that annex or amendment to an annex shall not enter into force until such time as the amendment to this Protocol enters into force.

7. Amendments to Annexes A and B to this Protocol shall be adopted and enter into force in accordance with the procedure set out in Article 20, provided that any amendment to Annex B shall be adopted only with the written consent of the Party concerned.

Article 22

1. Each Party shall have one vote, except as provided for in paragraph 2 below.

2. Regional economic integration organizations, in matters within their competence, shall exercise their right to vote with a number of votes equal to the number of their member States that are Parties to this Protocol. Such an organization shall not exercise its right to vote if any of its member States exercises its right, and vice versa.

Article 23

The Secretary-General of the United Nations shall be the Depositary of this Protocol.

Article 24

1. This Protocol shall be open for signature and subject to ratification, acceptance or approval by States and regional economic integration organizations which are Parties to the Convention. It shall be open for signature at United Nations Headquarters in New York from 16 March 1998 to 15 March 1999. This Protocol shall be open for accession from the day after the date on which it is closed for signature. Instruments of ratification, acceptance, approval or accession shall be deposited with the Depositary.

2. Any regional economic integration organization which becomes a Party to this Protocol without any of its member States being a Party shall be bound by all the obligations under this Protocol. In the case of such organizations, one or more of whose member States is a Party to this Protocol, the organization and its member States shall decide on their respective responsibilities for the performance of their obligations under this Protocol. In such cases, the organization and the member States shall not be entitled to exercise rights under this Protocol concurrently.

3. In their instruments of ratification, acceptance, approval or accession, regional economic integration organizations shall declare the extent of their competence with respect to the matters governed by this Protocol. These organizations shall also inform the Depositary, who shall in turn inform the Parties, of any substantial modification in the extent of their competence.

Article 25

1. This Protocol shall enter into force on the ninetieth day after the date on which not less than 55 Parties to the Convention, incorporating Parties included in Annex I which accounted in total for at least 55 per cent of the total carbon dioxide emissions for 1990 of the Parties included in Annex I, have deposited their instruments of ratification, acceptance, approval or accession.

2. For the purposes of this Article, "the total carbon dioxide emissions for 1990 of the Parties included in Annex I" means the amount communicated on or before the date of adoption of this Protocol by the Parties included in Annex I in their first national communications submitted in accordance with Article 12 of the Convention.

3. For each State or regional economic integration organization that ratifies, accepts or approves this Protocol or accedes thereto after the conditions set out in paragraph 1 above for entry into force have been fulfilled, this Protocol shall enter into force on the ninetieth day following the date of deposit of its instrument of ratification, acceptance, approval or accession.

4. For the purposes of this Article, any instrument deposited by a regional economic integration organization shall not be counted as additional to those deposited by States members of the organization.

Article 26

No reservations may be made to this Protocol.

Article 27

1. At any time after three years from the date on which this Protocol has entered into force for a Party, that Party may withdraw from this Protocol by giving written notification to the Depositary.

2. Any such withdrawal shall take effect upon expiry of one year from the date of receipt by the Depositary of the notification of withdrawal, or on such later date as may be specified in the notification of withdrawal.

3. Any Party that withdraws from the Convention shall be considered as also having withdrawn from this Protocol.

Article 28

The original of this Protocol, of which the Arabic, Chinese, English, French, Russian and Spanish texts are equally authentic, shall be deposited with the Secretary-General of the United Nations.

DONE at Kyoto this eleventh day of December one thousand nine hundred and ninety-seven.

IN WITNESS WHEREOF the undersigned, being duly authorized to that effect, have affixed their signatures to this Protocol on the dates indicated.

Annex A

Greenhouse gases

Carbon dioxide (CO_2)
Methane (CH_4)
Nitrous oxide (N_2O)
Hydrofluorocarbons (HFCs)
Perfluorocarbons (PFCs)
Sulphur hexafluoride (SF_6)

Sectors/source categories

Energy
- Fuel combustion
  - Energy industries
  - Manufacturing industries and construction
  - Transport
  - Other sectors
  - Other
- Fugitive emissions from fuels
  - Solid fuels
  - Oil and natural gas
  - Other

Industrial processes
- Mineral products
- Chemical industry
- Metal production
- Other production
- Production of halocarbons and sulphur hexafluoride
- Consumption of halocarbons and sulphur hexafluoride
- Other

Solvent and other product use

Agriculture
- Enteric fermentation
- Manure management
- Rice cultivation
- Agricultural soils
- Prescribed burning of savannas
- Field burning of agricultural residues
- Other

Waste

- Solid waste disposal on land
- Wastewater handling
- Waste incineration
- Other

Annex B

Party	Quantified emission limitation or reduction commitment (percentage of base year or period)
Australia	108
Austria	92
Belgium	92
Bulgaria*	92
Canada	94
Croatia*	95
Czech Republic*	92
Denmark	92
Estonia*	92
European Community	92
Finland	92
France	92
Germany	92
Greece	92
Hungary*	94
Iceland	110
Ireland	92
Italy	92
Japan	94
Latvia*	92
Liechtenstein	92
Lithuania*	92
Luxembourg	92
Monaco	92
Netherlands	92
New Zealand	100
Norway	101
Poland*	94
Portugal	92
Romania*	92
Russian Federation*	100
Slovakia*	92
Slovenia*	92
Spain	92
Sweden	92
Switzerland	92
Ukraine*	100
United Kingdom of Great Britain and Northern Ireland	92
United States of America	93

* Countries that are undergoing the process of transition to a market economy

Decision 2/CP.3

Methodological issues related to the Kyoto protocol

The Conference of the Parties,

Recalling its decisions 4/CP.1 and 9/CP.2,

Endorsing the relevant conclusions of the Subsidiary Body for Scientific and Technological Advice at its fourth session,[1]

1. *Reaffirms* that Parties should use the Revised 1996 Guidelines for National Greenhouse Gas Inventories of the Intergovernmental Panel on Climate Change to estimate and report on anthropogenic emissions by sources and removals by sinks of greenhouse gases not controlled by the Montreal Protocol;

2. *Affirms* that the actual emissions of hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride should be estimated, where data are available, and used for the reporting of emissions. Parties should make every effort to develop the necessary sources of data;

3. *Reaffirms* that global warming potentials used by Parties should be those provided by the Intergovernmental Panel on Climate Change in its Second Assessment Report ("1995 IPCC GWP values") based on the effects of the greenhouse gases over a 100-year time horizon, taking into account the inherent and complicated uncertainties involved in global warming potential estimates. In addition, for information purposes only, Parties may also use another time horizon, as provided in the Second Assessment Report;

4. *Recalls* that, under the Revised 1996 Guidelines for National Greenhouse Gas Inventories of the Intergovernmental Panel on Climate Change, emissions based upon fuel sold to ships or aircraft engaged in international transport should not be included in national totals, but reported separately; and *urges* the Subsidiary Body for Scientific and Technological Advice to further elaborate on the inclusion of these emissions in the overall greenhouse gas inventories of Parties;

5. *Decides* that emissions resulting from multilateral operations pursuant to the Charter of the United Nations shall not be included in national totals, but reported separately; other emissions related to operations shall be included in the national emissions totals of one or more Parties involved.

12th plenary meeting
11 December 1997

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[1] FCCC/SBSTA/1996/20, paras. 30 and 54.

Decision 3/CP.3

Implementation of Article 4, paragraphs 8 and 9, of the Convention

The Conference of the Parties,

Noting the provisions of Article 4, paragraphs 8 and 9, of the United Nations Framework Convention on Climate Change,

Noting further the provisions of Article 3 of the Convention and of the "Berlin Mandate" in its paragraph 1(b),[1]

1. *Requests* the Subsidiary Body for Implementation, at its eighth session, to undertake a process to identify and determine actions necessary to meet the specific needs of developing country Parties, specified under Article 4, paragraphs 8 and 9, of the Convention, arising from adverse effects of climate change and/or the impact of the implementation of response measures. Issues to be considered shall include actions related to funding, insurance and transfer of technology;

2. *Further requests* the Subsidiary Body for Implementation to report to the Conference of the Parties, at its fourth session, on the outcome of this process;

3. *Invites* the Conference of the Parties, at its fourth session, to take a decision on actions based on the conclusions and recommendations of this process.

12th plenary meeting
11 December 1997

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[1] Decision 1/CP.1.

Decision 4/CP.3

Article 4.2(f) of the Convention

The Conference of the Parties,

Recalling Article 4.2 (f) of the United Nations Framework Convention on Climate Change,

Having reviewed available information regarding amendments to the lists in Annexes I and II to the Convention,

Noting that the Parties concerned have granted their approval to be included in the list in Annex I to the Convention,

Bearing in mind the procedure in Article 4.2 (f) of the Convention,

1. *Decides* to amend the list in Annex I to the Convention by:

(a) Deleting the name of Czechoslovakia;

(b) Including the names of Croatia[a], the Czech Republic[a], Liechtenstein, Monaco, Slovakia[a] and Slovenia[a];

2. *Notes* that the entry into force of these amendments to the list included in Annex I to the Convention shall be subject to the same procedure as that for the entry into force of annexes to the Convention in accordance with Article 16.3 of the Convention.

12th plenary meeting
11 December 1997

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[a] Countries that are undergoing transition to a market economy

Decision 5/CP.3

Date and venue of the fourth session of the Conference of the Parties

The Conference of the Parties,

Recalling Article 7.4 of the United Nations Framework Convention on Climate Change,

Recalling General Assembly resolution 40/243 of 18 December 1985,

Having received an offer from the Government of Argentina to host the fourth session of the Conference of the Parties in Buenos Aires and to cover the related costs involved,

1. *Accepts with gratitude* the generous offer of the Government of Argentina to host the fourth session of the Conference of the Parties;

2. *Decides* that the fourth session of the Conference of the Parties shall be held in Buenos Aires, Argentina, from 2 to 13 November 1998;

3. *Requests* the Executive Secretary to conclude a host country agreement with the Government of Argentina on arrangements for the fourth session of the Conference of the Parties.

5th plenary meeting
5 December 1997

Decision 6/CP.3

Communications from Parties included in Annex I to the Convention

The Conference of the Parties,

Recalling the relevant provisions of the United Nations Framework Convention on Climate Change, its decision 2/CP.1 on review of first communications from the Parties included in Annex I to the Convention, decision 3/CP.1 on preparation and submission of national communications from the Parties included in Annex I to the Convention, decision 4/CP.1 on methodological issues and decision 9/CP.2 on the guidelines, schedule and process for consideration of communications from Parties included in Annex I to the Convention,

Having considered the relevant recommendations of the Subsidiary Body for Scientific and Technological Advice and those of the Subsidiary Body for Implementation,

1. *Calls upon* the Parties included in Annex I to the Convention (Annex I Parties), when submitting annually national greenhouse gas inventories, to follow the relevant parts of the revised UNFCCC guidelines for the preparation of national communications by Annex I Parties, as well as the relevant conclusions of the fourth session of the Subsidiary Body for Scientific and Technological Advice;

2. *Requests* the Convention secretariat:

(a) To prepare a full compilation and synthesis of second national communications from Annex I Parties for consideration at its fourth session;

(b) To collect, process and publish, on a regular basis, national greenhouse gas inventories submitted annually by Annex I Parties in accordance with decision 9/CP.2. In those years when the compilation and synthesis of national communications is prepared inventory data should be included. Publication of inventory data may be accompanied by relevant documentation prepared by the secretariat, for example, on evaluating compliance with the Intergovernmental Panel on Climate Change guidelines or addressing methodological or other issues related to reporting greenhouse gas emissions. It may also include or refer to relevant data from authoritative sources;

3. *Decides* that:

(a) In-depth reviews of second national communications from Annex I Parties should, as a general rule, include visits of review teams co-ordinated by the secretariat, based on the schedule of these reviews and on a visit programme agreed between the host countries and the secretariat. Parties concerned are urged to submit their comments on the draft in-depth review reports produced by the review teams, if possible not later than eight weeks following receipt of the drafts;

(b) Executive summaries of national communications will be published in their original language as official UNFCCC documents, and also translated into the other official languages of the United Nations if they are less than 15 pages long in standard format. Full texts of the in-depth review reports will be published as official UNFCCC documents and translated into the other official languages of the United Nations.

2nd plenary meeting
1 December 1997

Decision 7/CP.3

Cooperation with the Intergovernmental Panel on Climate Change

The Conference of the Parties,

Reaffirming its decision 6/CP.2, paragraph 5, in which it urged continuing cooperation between the Convention bodies and the Intergovernmental Panel on Climate Change,

1. *Expresses* appreciation to the Intergovernmental Panel on Climate Change for its contribution to the Convention process, particularly through its prompt response to requests from the Subsidiary Body for Scientific and Technological Advice for technical papers, special reports and Guidelines for National Greenhouse Gas Inventories, as well as for its plans for the preparation of the Third Assessment Report; and, in this connection, *requests* the Subsidiary Body for Scientific and Technological Advice to give further consideration to issues related to the work of the Intergovernmental Panel on Climate Change and to formulate policy-relevant questions which should be addressed in the Third Assessment Report;

2. *Thanks* the Chairman Emeritus of the Intergovernmental Panel on Climate Change, Professor Bert Bolin, for his outstanding work and his valuable scientific contribution to the Convention process;

3. *Invites* the subsidiary bodies of the Convention, in particular the Subsidiary Body for Scientific and Technological Advice, to continue their cooperation with the Intergovernmental Panel on Climate Change.

2nd plenary meeting
1 December 1997

Decision 8/CP.3

Development of observational networks of the climate system

The Conference of the Parties,

Recalling Article 4.1(g) and Article 5 of the United Nations Framework Convention on Climate Change,

Noting the importance of the observations, analysis and research relevant to the various components of the climate system,

1. *Expresses* appreciation of the work carried out by the relevant intergovernmental organizations, particularly the development of such observational programmes as the Global Climate Observing System, the Global Ocean Observing System and the Global Terrestrial Observing System;

2. *Recognizes* the concerns raised by the relevant intergovernmental organizations with regard to the long-term sustainability of these observational systems;

3. *Urges* Parties to provide the necessary resources to reverse the decline in the existing observational networks and to support the regional and global observational systems being developed under the Global Climate Observing System, the Global Ocean Observing System and the Global Terrestrial Observing System, through appropriate funding mechanisms;

4. *Requests* the Subsidiary Body for Scientific and Technological Advice, with the assistance of the secretariat and in consultation with the Intergovernmental Panel on Climate Change, to consider the adequacy of these observational systems and to report on its conclusions to the Conference of the Parties at its fourth session.

2nd plenary meeting
1 December 1997

Decision 9/CP.3

Development and transfer of technologies

The Conference of the Parties,

Recalling the relevant provisions of the programme for the further implementation of Agenda 21 on the transfer of environmentally sound technologies adopted by the United Nations General Assembly at its nineteenth special session,

Noting the role of the public and private sectors in developing and disseminating environmentally sound and economically viable technologies related to the mitigation of, and adaptation to, climate change,

Recognizing the progress made by countries in fostering the institutional and regulatory environment necessary for the introduction of environmentally sound technologies and the need for continued efforts by Parties to remove existing market barriers to technology dissemination,

Recalling its decisions 13/CP.1 and 7/CP.2 on transfer of technology,

Having considered the progress reports presented by the Convention secretariat on the development and transfer of technology,[1]

1. *Reaffirms* its decisions 13/CP.1 and 7/CP.2 on transfer of technology;

2. *Requests* the Convention secretariat,

(a) To continue its work on the synthesis and dissemination of information on environmentally sound technologies and know-how conducive to mitigating, and adapting to, climate change; for example, by accelerating the development of methodologies for adaptation technologies, in particular decision tools to evaluate alternative adaptation strategies, bearing in mind the work programme on methodological issues approved by the Subsidiary Body for Scientific and Technological Advice at its sixth session;[2]

(b) To consult with the Global Environment Facility and other relevant international organizations, and solicit information on their capabilities and abilities to support the work of (an) international technology information centre(s), as well as national and regional centres, and to enhance support for national and regional centres, and to report to the Subsidiary Body for Scientific and Technological Advice and the Subsidiary Body for Implementation on its findings;

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[1] FCCC/SB/1997/1, 3 and 4, and FCCC/SBSTA/1997/10.

[2] FCCC/SBSTA/1997/6, section IV, A

(c) To consider specific case studies, as part of its work on terms of transfer of technologies, drawing on the experience of Parties, including demonstration projects, with the aim of evaluating barriers to the introduction and implementation of environmentally sound technologies and know-how, and of promoting their practical application;

3. *Requests* the Subsidiary Body for Implementation to consider options for funding (an) international technology information centre(s) and enhancing support for national or regional centres;

4. *Requests* the Subsidiary Body for Scientific and Technological Advice to forward any conclusions regarding technology information centres and enhancing support for national or regional centres to the Subsidiary Body for Implementation for consideration;

5. *Urges* Parties:

(a) To create an enabling environment to help further stimulate private-sector investment in, and transfer of, environmentally sound technologies; and

(b) To improve reporting in national communications on technology needs and technology transfer activities, as indicated in the reporting guidelines adopted by the Parties.

2nd plenary meeting
1 December 1997

Decision 10/CP.3

Activities implemented jointly under the pilot phase

The Conference of the Parties,

Acknowledging the contributions of the Parties which submitted reports on activities implemented jointly under the pilot phase,

Noting the progress made in the pilot phase as evidenced in the synthesis report on activities implemented jointly[1] and the concise update on contact and activity information,[2]

1. *Takes note* of the synthesis report on activities implemented jointly;[1]

2. *Reaffirms* its decision 5/CP.1 on activities implemented jointly under the pilot phase;

3. *Adopts* the uniform reporting format contained in the report of the Subsidiary Body for Scientific and Technological Advice on the work of its fifth session,[3] and *invites* Parties to report in accordance with that format and to provide inputs to the secretariat on their experience in using it, so that, if necessary, changes can be incorporated.

2nd plenary meeting
1 December 1997

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[1] FCCC/SBSTA/1997/12 and Corr.1-2, and Add.1

[2] FCCC/SBSTA/1997/INF.3.

[3] FCCC/SBSTA/1997/4.

Decision 11/CP.3

Review of the financial mechanism

The Conference of the Parties

1. *Takes note of* the review process undertaken by the Subsidiary Body for Implementation in accordance with decision 11/CP.2;

2. *Decides* to continue the review process through the Subsidiary Body for Implementation, in accordance with the criteria established in the guidelines adopted by the Subsidiary Body for Implementation at its fifth session;[1]

3. *Reaffirms* its decision 9/CP.1;

4. *Requests* the secretariat to report to the Subsidiary Body for Implementation in accordance with paragraph 2 above.

2nd plenary meeting
1 December 1997

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[1] FCCC/SBI/1997/6, annex II

Decision 12/CP.3

Annex to the Memorandum of Understanding on the determination of funding necessary and available for the implementation of the Convention

The Conference of the Parties

1. *Takes note* of the approval by the Council of the Global Environment Facility of the annex to the Memorandum of Understanding between the Conference of the Parties and the Council of the Global Environment Facility;

2. *Decides* to approve the annex to the Memorandum of Understanding, thereby bringing it into force.

2nd plenary meeting
1 December 1997

Decision 13/CP.3

Division of labour between the Subsidiary Body for Implementation and the Subsidiary Body for Scientific and Technological Advice

The Conference of the Parties,

Recalling Articles 9 and 10 of the United Nations Framework Convention on Climate Change,

Recalling also its decision at its second session that the question of the division of labour between the Subsidiary Body for Scientific and Technological Advice and the Subsidiary Body for Implementation should be taken up by the Conference of the Parties at its third session on the basis of recommendations made to it by the Chairmen of the two subsidiary bodies,[1]

Having considered the recommendations made by the Chairmen, through the conclusions of the Subsidiary Body for Scientific and Technological Advice and the Subsidiary Body for Implementation, as included in the reports of their sixth sessions,[2]

Desiring to elaborate further the division of labour between the Subsidiary Body for Scientific and Technological Advice and the Subsidiary Body for Implementation,

1. *Reaffirms* that the division of labour is governed by Articles 9 and 10 of the Convention, and by decision 6/CP.1 and other relevant decisions of the Conference of the Parties;

2. *Recalls* that, as indicated in decision 6/CP.1, the role of the subsidiary bodies can be broadly characterized as follows:

(a) The Subsidiary Body for Scientific and Technological Advice will be the link between the scientific, technical and technological assessments and the information provided by competent international bodies, and the policy-oriented needs of the Conference of the Parties;

(b) The Subsidiary Body for Implementation will develop recommendations to assist the Conference of the Parties in its review and assessment of the implementation of the Convention and in the preparation and implementation of its decisions;

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[1] FCCC/CP/1996/15/Add.1, section III, 4.

[2] FCCC/SBSTA/1997/6 and FCCC/SBI/1997/16.

3. *Decides* that the consideration of issues which are pertinent to both bodies should take place in a way which is efficient in the use of time during meetings, in order to avoid confusion and to reduce the overall workload. Therefore, in general, one of the bodies will take the overall responsibility in considering an issue. If necessary, it will request adequate and specific inputs from the other body. Where overall responsibility is not assigned, agendas should be organized to ensure that the Subsidiary Body for Scientific and Technological Advice and the Subsidiary Body for Implementation avoid dealing with such issues in parallel sessions. On issues where this is not possible, consideration should be given to holding ad hoc joint sessions of the Subsidiary Body for Scientific and Technological Advice and the Subsidiary Body for Implementation. On this basis, the provisions above are clarified as follows:

National communications from Parties

(a) The Subsidiary Body for Implementation will have the overall responsibility for:

(i) Developing guidelines on the processes for consideration of national communications;

(ii) Considering the information contained in national communications, other relevant documentation and compilation and synthesis reports, with a view to assisting the Conference of the Parties in undertaking its tasks under Article 7.2(e) of the Convention;

(b) In co-operation with the Subsidiary Body for Implementation, the Subsidiary Body for Scientific and Technological Advice will have responsibility for:

(i) Developing guidelines for the provision of comparable information, including all related methodological issues;

(ii) Considering, upon the request of the Subsidiary Body for Implementation, as appropriate, national communications and other relevant documentation, such as technical papers, with the aim of, *inter alia*, verifying methodologies used and making recommendations on their refinement, preparing scientific assessments on the effects of measures taken in the implementation of the Convention, reviewing projections and their assumptions, and assessing the comprehensiveness and effectiveness of mitigation and adaptation measures;

Development and transfer of technology

(c) The Subsidiary Body for Implementation will, with inputs from the Subsidiary Body for Scientific and Technological Advice as appropriate, have responsibilities for assisting the

Conference of the Parties in the assessment and review of the effective implementation of the Convention with respect to the development and transfer of technology;

(d) As stipulated in the Convention, and as decided by the Conference of the Parties in decision 6/CP.1, the Subsidiary Body for Scientific and Technological Advice will have responsibility for providing advice on all scientific, technological and methodological aspects of the development and transfer of technology;

Consultations with non-governmental organizations

(e) Taking into account the competence of each subsidiary body, the Subsidiary Body for Implementation will have overall responsibility for all policy questions and relevant inputs related to issues dealing with consultation with non-governmental organizations, as appropriate;

(f) Should the Subsidiary Body for Scientific and Technological Advice or any other subsidiary body feel that non-governmental organizations could provide relevant inputs on an item being considered, that body could seek and consider such inputs;

(g) Provisional accreditation of individual non-governmental organizations will be the responsibility of the body concerned;

Activities implemented jointly

(h) The Subsidiary Body for Scientific and Technological Advice will have the responsibility for:

(i) Developing the framework for reporting, including consideration of scientific, technical and methodological aspects of the reports;

(ii) Preparing a synthesis report of activities for the Conference of the Parties;

(i) The Subsidiary Body for Implementation will have the responsibility for assisting the Conference of the Parties in reviewing the progress of the activities implemented jointly under the pilot phase, on the basis of inputs by the Subsidiary Body for Scientific and Technological Advice;

Research and systematic observation

(j) In accordance with Article 5 of the Convention, the Subsidiary Body for Scientific and Technological Advice will have the overall responsibility for issues related to research and systematic observation, drawing, where necessary, upon the Subsidiary Body for Implementation. The Subsidiary Body for Scientific and Technological Advice will also play a co-ordinating role in such activities related to climate change relevant to the implementation of the Convention;

(k) The Subsidiary Body for Implementation, with inputs from the Subsidiary Body for Scientific and Technological Advice as appropriate, will have the responsibility for assisting the Conference of the Parties in the assessment and review of the effective implementation of the Convention with respect to research and systematic observation;

Education, training and public awareness

(l) In further clarification of decision 6/CP.1, the Subsidiary Body for Scientific and Technological Advice will have the overall responsibility for providing advice on educational, training and public awareness programmes, as well as public access to information. When considering such issues, the Subsidiary Body for Scientific and Technological Advice will draw upon, *inter alia*, relevant international organizations;

(m) The Subsidiary Body for Implementation, with inputs from the Subsidiary Body for Scientific and Technological Advice as appropriate, will have responsibility for assisting the Conference of the Parties in the assessment and review of the effective implementation of the Convention with respect to education, training, and public awareness.

2nd plenary meeting
1 December 1997

Decision 14/CP.3

Future work of the Ad Hoc Group on Article 13

The Conference of the Parties,

Recalling Article 13 of the United Nations Framework Convention on Climate Change, and decisions 20/CP.1 and 4/CP.2,

Having considered the report of the Ad Hoc Group on Article 13 on the work of its fifth session,[1] at which the Group agreed on a set of functions and procedures that could serve as a basis for further discussion in its consideration of a multilateral consultative process and its design,

Taking note that the Ad Hoc Group on Article 13 could not complete its work before the third session of the Conference of the Parties,

1. *Decides*, pursuant to its decision 4/CP.2, that the work of the Ad Hoc Group on Article 13 should continue beyond the third session of the Conference of the Parties;

2. *Invites* the Group to complete its work before the fourth session of the Conference of the Parties and, pursuant to decision 20/CP.1, provide the Conference of the Parties with a report on its findings;

3. *Requests* the Group to report to the Conference of the Parties at its fourth session on the progress of its work, if its work has not been completed by that time.

2nd plenary meeting
1 December 1997

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[1] FCCC/AG13/1997/4.

Decision 15/CP.3

Programme budget for the biennium 1998-1999

The Conference of the Parties,

Recalling paragraph 4 of the financial procedures for the Conference of the Parties,

Having considered the proposed budget for the biennium 1998-1999 submitted by the Executive Secretary,[1]

Noting the annual contribution of the host Government, DM 1.5 million, which offsets planned expenditures,

1. *Approves* the programme budget for the biennium 1998-1999, amounting to $ 21,345,900,[2] for the purposes specified in table 1 below;

2. *Approves* the staffing table for the programme budget, including the post of the Executive Secretary at the level of Assistant Secretary-General and two other senior posts at the level of D-2, as contained in table 2 below;

3. *Approves* a contingency budget for conference servicing, amounting to $ 5,184,900, to be added to the programme budget for the coming biennium in the event that the General Assembly of the United Nations decides not to provide resources for these activities in the regular United Nations budget for the biennium 1998-1999 (see table 3 below);[3]

4. *Requests* the Executive Secretary to report to the Subsidiary Body for Implementation at its eighth session on the implementation of paragraph 3 above, and on the deployment of staff and financial resources to perform the tasks arising from the decision to adopt the Kyoto Protocol;

5. *Authorizes* the Executive Secretary to make transfers, between each of the main

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[1] FCCC/SBI/1997/10. In this connection, see also document FCCC/CP/1997/INF.1.

[2] This figure would be offset by the annual contributions of the host Government, amounting to DM 3 million, resulting in a net figure of $ 19,570,700 to be met in the form of contributions from Parties.

[3] By its resolution 52/119 (dated 18 December 1997), the General Assembly of the United Nations decided to include eight weeks of conference-servicing facilities for the Conference of the Parties and its subsidiary bodies in its calendar of conferences and meetings for the biennium 1998-1999. As a result, the contingency budget for conference servicing will not be included in the UNFCCC programme budget for the same biennium.

appropriation lines set out in table 1 below, up to an aggregate limit of 15 per cent of total estimated expenditure for those appropriation lines, provided that a further limitation of up to minus 25 per cent of each such appropriation line shall apply;

6. *Decides* to maintain the level of the working capital reserve at 8.3 per cent of the estimated expenditure;

7. *Invites* all Parties to the Convention to note that contributions to the core budget are due on 1 January of each year in accordance with paragraph 8(b) of the financial procedures and to pay promptly and in full, for each of the years 1998 and 1999, the contributions required to finance expenditures approved under paragraph 1 above, as offset by estimated contributions noted under the third paragraph of the preamble to this decision, and the contributions which may result from the decision of the General Assembly referred to in paragraph 3 above;

8. *Takes note* of the funding estimates for the Trust Fund for Participation in the United Nations Framework Convention on Climate Change Process and the Trust Fund for Supplementary Activities under the United Nations Framework Convention on Climate Change specified by the Executive Secretary and included in table 5 below, and *invites* Parties to make contributions to these funds;

9. *Requests* the Executive Secretary to report to the Conference of the Parties at its fourth session on income and budget performance, and to propose any adjustments that might be needed in the Convention budget for the biennium 1998-1999.

Table 1 Programme budget for the biennium 1998-1999 (US$ thousand)

Expenditures	1998	1999
I. Programmes		
Executive Direction and Management	621.3	642.8
Science and Technology	2,223.1	2,779.4
Implementation	2,333.6	2,553.0
Conference and Information Support	1,500.1	1,901.2
Resources, Planning and Coordination	1,599.5	1,807.6
Activities related to the Kyoto Protocol	242.3	462.9
Subtotal (I)	8,519.8	10,146.9
II. Payments to the United Nations		
Overhead charge[a]	1,107.6	1,319.1
Subtotal (II)	1,107.6	1,319.1
III. Working capital reserve[b]	99.7	152.6
Subtotal (III)	99.7	152.6
Total expenditure (I+II+III)	9,727.1	11,618.6
Income		
Contribution from the host Government	887.6	887.6
Total income	887.6	887.6
NET TOTAL	8,839.5	10,731

[a] Standard 13 per cent applied by the United Nations for administrative support.

[b] In accordance with paragraph 14 of the financial procedures (see decision 15/CP.1). This will bring the level of the working capital reserve to $799,100 in 1998 and $951,700 in 1999 (see paragraphs 17-19 of the financial procedures).

Table 2: Programme budget staffing table 1998-1999

		1998	1999
A.	Professional category and above		
	Executive Secretary	1	1
	D-2	2	2
	D-1	3.83	5
	P-5	5.75	6
	P-4	7.5	8
	P-3	9.5	12
	P-2	4.25	5
	Subtotal (A)	33.83	39
B.	General Service category	21	23
	Subtotal (B)	21	23
	TOTAL (A+B)	54 83	62

Table 3: Resource requirements for the conference servicing contingency (US$ thousand)

Item of expenditure		1998	1999
I.	Meeting servicing[a]	419.4	431.5
II.	Documentation[b]	698.5	737.4
III.	Other requirements[c]	707.5	728.1
IV.	Travel of staff to meetings[d]	265.5	265.5
V.	Miscellaneous[e]	10.5	10.5
VI.	Contingencies and exchange rate fluctuation	63.0	65.2
	Subtotal	2,164.4	2,238.2
VII.	Overhead charge[f]	281.4	291.0
VIII.	Working Capital Reserve[g]	203.0	6.9
TOTAL		2,648.8	2536.1

Table 4: Staffing requirements for the conference servicing contingency

	1998	1999
A. Professional category and above		
P-4	1	1
Subtotal (A)	1	1
B. General Service category	4	4
Subtotal (B)	4	4
TOTAL (A+B)	5	5

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[a] Includes interpretation and meeting room staff.

[b] Includes revision, translation, typing, reproduction and distribution of pre-, in- and post-session documentation.

[c] Includes remote translation requirements, key supervisory staff, freight, communications.

[d] Includes travel of interpreters and key supervisory staff, including planning missions.

[e] Includes estimated cost of initial stock of meeting stationery and supplies

[f] Standard 13 per cent applied by the United Nations for administrative support.

[g] In accordance with paragraph 14 of the financial procedures. The 1998 amount has been calculated as 8.3 per cent of the subtotal of I-VII; the 1999 amount has been calculated as the amount required to bring the carried-over 1998 reserve to 8.3 per cent of the subtotal of I-VII for 1999.

Table 5: Summary of other voluntary funding resource estimates for the biennium 1998-1999 (US$ thousand)

Proposed source of funding	1998	1999
Trust Fund for Participation in the UNFCCC Process	2,256.1	2,324.4
Trust Fund for Supplementary Activities	2,062.6	2,086.2
TOTAL	4,318.7	4,410.6

12th plenary meeting
11 December 1997

Decision 16/CP.3

Financial performance of the Convention in the biennium 1996-1997

The Conference of the Parties,

Recalling its decision 16/CP.2, paragraph 14, whereby it requested the Executive Secretary to submit to the Conference of the Parties at its third session a further report on financial performance for the biennium 1996-1997,

Recalling also the financial rules for the Conference of the Parties,

1. *Takes note* of the information provided in documents FCCC/SBI/1997/18 and FCCC/SBI/1997/INF.7;

2. *Approves* the creation of a new trust fund for the special annual contribution of DM 3.5 million from the Government of Germany to finance events in Germany, made in accordance with the bilateral arrangements between the Government of Germany and the Convention secretariat, and *requests* the Executive Secretary to request the Secretary-General of the United Nations to establish the new trust fund, to be managed by the Executive Secretary;

3. *Urges* Parties that have still not paid their 1996 and/or 1997 contributions to the core budget to do so without delay;

4. *Requests* the Executive Secretary to submit to the Conference of the Parties at its fourth session, through the Subsidiary Body for Implementation, as appropriate, a final report on financial performance in the biennium 1996-1997, including audited financial statements, and an initial report on financial performance in 1998;

5. *Approves* transfers between the main appropriation lines to cover over-expenditures, for the Policy-making organs programme and the Implementation and planning programme, in excess of the 15 per cent transfer within each of the main appropriation lines that the Executive Secretary is at present authorized to make.[1]

2nd plenary meeting
1 December 1997

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[1] See decision 17/CP.1, para. 5.

Decision 17/CP.3

Arrangements for administrative support to the Convention secretariat

The Conference of the Parties,

Recalling the arrangements proposed by the Secretary-General of the United Nations for administrative support to the Convention secretariat,[1] provisionally accepted by the Conference of the Parties at its first session by its decision 14/CP.1,

1. *Takes note* of the information contained in document FCCC/SBI/1997/INF.2;

2. *Requests* the Executive Secretary to continue his discussions with the United Nations regarding administrative arrangements for the Convention, and to inform the Conference of the Parties, through the Subsidiary Body for Implementation, as appropriate, of any significant developments.

2nd plenary meeting
1 December 1997

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[1] FCCC/CP/1995/5/Add.4.

Decision 18/CP.3

Volume of documentation

The Conference of the Parties,

Recalling its decision 17/CP.2, paragraph 2, whereby it requested the Executive Secretary to submit to the Subsidiary Body for Implementation, at its fifth session, further options for reducing the cost of documentation for the meetings of the Conference of the Parties and its subsidiary bodies,

1. *Takes note* of the efforts of the Convention secretariat to reduce the volume of documentation, as indicated in the note by the secretariat on volume of documentation;[1]

2. *Requests* the Executive Secretary to explore with the United Nations the possibility of ensuring unrestricted access to all language versions of the documents of the United Nations Framework Convention on Climate Change that the United Nations makes available on its optical disk system through a restricted page on the World Wide Web;

3. *Invites* the Parties:

(a) To limit the volume of their submissions for circulation to Convention bodies, including those that do not require translation;

(b) To focus the content of submissions on material pertinent to the forthcoming sessions of the subsidiary bodies and to seek to avoid repetition of previously presented statements;

(c) To limit their requests for numbers of hard copies of documents;

(d) To limit the requests for documents that need to be translated;

(e) To schedule the delivery of documents in a timely manner that corresponds to the capacity of the Convention bodies to consider them;

4. *Notes* the intention of the Executive Secretary to advise presiding officers on the feasibility of producing, in a timely manner, the documentation envisaged in the conclusions of subsidiary bodies, before those conclusions are adopted.

2nd plenary meeting
1 December 1997

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[1] FCCC/SBI/1997/12, paras. 9-10.

II. RESOLUTION ADOPTED BY THE CONFERENCE OF THE PARTIES

Resolution 1/CP.3

Expression of gratitude to the Government and people of Japan

The Conference of the Parties,

Having met in Kyoto from 1 to 11 December 1997 at the invitation of the Government of Japan,

1. *Expresses its profound gratitude* to the Government of Japan for having made it possible for the third session of the Conference of the Parties to be held in Kyoto and for the excellent facilities, staff and services so graciously placed at its disposal;

2. *Requests* the Government of Japan to convey to the Prefecture and City of Kyoto, and to the people of Japan, the gratitude of the Conference of the Parties for the hospitality and warm welcome extended to the participants.

12th plenary meeting
11 December 1997

III. OTHER ACTION TAKEN BY THE CONFERENCE OF THE PARTIES

1. Second review of the adequacy of Article 4.2(a) and (b) of the Convention

At its 3rd plenary meeting, on 3 December 1997, the Conference of the Parties decided to place the issue of the second review of the adequacy of Article 4.2(a) and (b) of the Convention on the agenda for its fourth session, and to request the subsidiary bodies and the secretariat to make all necessary preparations to facilitate future consideration of that item (see Part One, section III D, para. 63 of the present report).

2. Request by Turkey to be deleted from the lists in Annexes I and II to the Convention

At its 12th plenary meeting, on 11 December 1997, the Conference of the Parties requested the Subsidiary Boy for Implementation, at its eighth session, to consider the request to delete the name of Turkey from the lists in Annexes I and II to the Convention, and to present a report to the Conference of the Parties at its fourth session for consideration and definitive action (see Part One, section III E, para. 68 of the present report).

3. Proposal by Brazil in document FCCC/AGBM/1997/MISC.1/Add.3

At its 5th plenary meeting, on 5 December 1997, the Conference of the Parties decided that the proposal presented by Brazil in document FCCC/AGBM/1997/MISC.1/Add.3 should be referred to the Subsidiary Body for Scientific and Technological Advice for its advice regarding the methodological and scientific aspects. It authorized the Subsidiary Body for Scientific and Technological Advice to seek inputs, as appropriate, from its roster of experts and from the Intergovernmental Panel on Climate Change, and requested it to make its advice available to the Conference of the Parties at its fourth session (see Part One, section III F, para. 69 of the present report).

4. Calendar of meetings of Convention bodies 1998-1999

At its 5th plenary meeting, on 5 December 1997, the Conference of the Parties adopted the following calendar of meetings of Convention bodies in 1998-1999 (see Part One, section II G, para. 35 of the present report):

1. First sessional period in 1998: from 2 to 12 June;

2. Second sessional period in 1998: from 2 to 13 November;

3. First sessional period in 1999: from 31 May to 11 June;

4. Second sessional period in 1999: from 25 October to 5 November.

Annex

Table: Total carbon dioxide emissions of Annex I Parties in 1990, for the purposes of Article 25 of the Kyoto Protocol [a]

Party	Emissions (Gg)	Percentage
Australia	288,965	2.1
Austria	59,200	0.4
Belgium	113,405	0.8
Bulgaria	82,990	0.6
Canada	457,441	3.3
Czech Republic	169,514	1.2
Denmark	52,100	0.4
Estonia	37,797	0.3
Finland	53,900	0.4
France	366,536	2.7
Germany	1,012,443	7.4
Greece	82,100	0.6
Hungary	71,673	0.5
Iceland	2,172	0.0
Ireland	30,719	0.2
Italy	428,941	3.1
Japan	1,173,360	8.5
Latvia	22,976	0.2
Liechtenstein	208	0.0
Luxembourg	11,343	0.1
Monaco	71	0.0
Netherlands	167,600	1.2
New Zealand	25,530	0.2
Norway	35,533	0.3
Poland	414,930	3.0
Portugal	42,148	0.3
Romania	171,103	1.2
Russian Federation	2,388,720	17.4
Slovakia	58,278	0.4
Spain	260,654	1.9
Sweden	61,256	0.4
Switzerland	43,600	0.3
United Kingdom of Great Britain and Northern Ireland	584,078	4.3
United States of America	4,957,022	36.1
Total	**13,728,306**	**100.0**

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[a] Data based on the information from the 34 Annex I Parties that submitted their first national communications on or before 11 December 1997, as compiled by the secretariat in several documents (A/AC.237/81; FCCC/CP/1996/12/Add.2 and FCCC/SB/1997/6). Some of the communications included data on CO2 emissions by sources and removals by sinks from land-use change and forestry, but since different ways of reporting were used these data are not included.

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UNITED NATIONS

Framework Convention on Climate Change

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CONFERENCE OF THE PARTIES

REPORT OF THE CONFERENCE OF THE PARTIES ON ITS THIRD SESSION, HELD AT KYOTO FROM 1 TO 11 DECEMBER 1997

Corrigendum

Page 17, section J. Attendance, paragraph 40

Line 2: *for* 158 *read* 159

After Niger *insert* Nigeria

UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE

The Parties to this Convention,

Acknowledging that change in the Earth's climate and its adverse effects are a common concern of humankind,

Concerned that human activities have been substantially increasing the atmospheric concentrations of greenhouse gases, that these increases enhance the natural greenhouse effect, and that this will result on average in an additional warming of the Earth's surface and atmosphere and may adversely affect natural ecosystems and humankind,

Noting that the largest share of historical and current global emissions of greenhouse gases has originated in developed countries, that per capita emissions in developing countries are still relatively low and that the share of global emissions originating in developing countries will grow to meet their social and development needs,

Aware of the role and importance in terrestrial and marine ecosystems of sinks and reservoirs of greenhouse gases,

Noting that there are many uncertainties in predictions of climate change, particularly with regard to the timing, magnitude and regional patterns thereof,

Acknowledging that the global nature of climate change calls for the widest possible cooperation by all countries and their participation in an effective and appropriate international response, in accordance with their common but differentiated responsibilities and respective capabilities and their social and economic conditions,

Recalling the pertinent provisions of the Declaration of the United Nations Conference on the Human Environment, adopted at Stockholm on 16 June 1972,

Recalling also that States have, in accordance with the Charter of the United Nations and the principles of international law, the sovereign right to exploit their own resources pursuant to their own environmental and developmental policies, and the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction,

Reaffirming the principle of sovereignty of States in international cooperation to address climate change,

Recognizing that States should enact effective environmental legislation, that environmental standards, management objectives and priorities should reflect the environmental and developmental context to which they apply, and that standards applied by some countries may be inappropriate and of unwarranted economic and social cost to other countries, in particular developing countries, Recalling the provisions of General Assembly resolution 44/228 of 22 December 1989 on the United Nations Conference on Environment and Development, and resolutions 43/53 of 6 December 1988, 44/207 of 22 December 1989, 45/212 of 21 December 1990 and 46/169 of 19 December 1991 on protection of global climate for present and future generations of mankind,

Recalling also the provisions of General Assembly resolution 44/206 of 22 December 1989 on the possible adverse effects of sea-level rise on islands and coastal areas, particularly low-lying coastal areas and the pertinent provisions of General Assembly resolution 44/172 of 19 December 1989 on the implementation of the Plan of Action to Combat Desertification,

Recalling further the Vienna Convention for the Protection of the Ozone Layer, 1985, and the Montreal Protocol on Substances that Deplete the Ozone Layer, 1987, as adjusted and amended on 29 June 1990,

Noting the Ministerial Declaration of the Second World Climate Conference adopted on 7 November 1990,

Conscious of the valuable analytical work being conducted by many States on climate change and of the important contributions of the World Meteorological Organization, the United Nations Environment Programme and other organs, organizations and bodies of the United Nations system, as well as other international and intergovernmental bodies, to the exchange of results of scientific research and the coordination of research,

Recognizing that steps required to understand and address climate change will be environmentally, socially and economically most effective if they are based on relevant scientific, technical and economic considerations and continually re-evaluated in the light of new findings in these areas,

Recognizing that various actions to address climate change can be justified economically in their own right and can also help in solving other environmental problems,

Recognizing also the need for developed countries to take immediate action in a flexible manner on the basis of clear priorities, as a first step towards comprehensive response strategies at the global, national and, where agreed, regional levels that take into account all greenhouse gases, with due consideration of their relative contributions to the enhancement of the greenhouse effect,

Recognizing further that low-lying and other small island countries, countries with low-lying coastal, arid and semi-arid areas or areas liable to floods, drought and desertification, and developing countries with fragile mountainous ecosystems are particularly vulnerable to the adverse effects of climate change, Recognizing the special difficulties of those countries, especially developing countries, whose economies are particularly dependent on fossil fuel production, use and exportation, as a consequence of action taken on limiting greenhouse gas emissions,

Affirming that responses to climate change should be coordinated with social and economic development in an integrated manner with a view to avoiding adverse impacts on the latter, taking into full account the legitimate priority needs of developing countries for the achievement of sustained economic growth and the eradication of poverty,

Recognizing that all countries, especially developing countries, need access to resources required to achieve sustainable social and economic development and that, in order for developing countries to progress towards that goal, their energy consumption will need to grow taking into account the possibilities for achieving greater energy efficiency and for controlling greenhouse gas emissions in general, including through the application of new technologies on terms which make such an application economically and socially beneficial,

Determined to protect the climate system for present and future generations,

Have agreed as follows:

ARTICLE 1: DEFINITIONS*

For the purposes of this Convention:

1. "Adverse effects of climate change" means changes in the physical environment or biota resulting from climate change which have significant deleterious effects on the composition, resilience or productivity of natural and managed ecosystems or on the operation of socio-economic systems or on human health and welfare.

2. "Climate change" means a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.

3. "Climate system" means the totality of the atmosphere, hydrosphere, biosphere and geosphere and their interactions.

4. "Emissions" means the release of greenhouse gases and/or their precursors into the atmosphere over a specified area and period of time.

5. "Greenhouse gases" means those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and re-emit infrared radiation

6. "Regional economic integration organization" means an organization constituted by sovereign States of a given region which has competence in respect of matters governed by this Convention

*Titles of articles are included solely to assist the reader.

or its protocols and has been duly authorized, in accordance with its internal procedures, to sign, ratify, accept, approve or accede to the instruments concerned.

7. "Reservoir" means a component or components of the climate system where a greenhouse gas or a precursor of a greenhouse gas is stored.

8. "Sink" means any process, activity or mechanism which removes a greenhouse gas, an aerosol or a precursor of a greenhouse gas from the atmosphere.

9. "Source" means any process or activity which releases a greenhouse gas, an aerosol or a precursor of a greenhouse gas into the atmosphere.

ARTICLE 2: OBJECTIVE

The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.

ARTICLE 3: PRINCIPLES

In their actions to achieve the objective of the Convention and to implement its provisions, the Parties shall be guided, inter alia, by the following:

1. The Parties should protect the climate system for the benefit of present and future generations of humankind, on the basis of equity and in accordance with their common but differentiated responsibilities and respective capabilities. Accordingly, the developed country Parties should take the lead in combating climate change and the adverse effects thereof.

2. The specific needs and special circumstances of developing country Parties, especially those that are particularly vulnerable to the adverse effects of climate change, and of those Parties, especially developing country Parties, that would have to bear a disproportionate or abnormal burden under the Convention, should be given full consideration.

3. The Parties should take precautionary measures to anticipate, prevent or minimize the causes of climate change and mitigate its adverse effects. Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing such measures, taking into account that policies and measures to deal with climate change should be cost-effective so as to ensure global benefits at the lowest possible cost. To achieve this, such policies and measures should take into account different socio-economic contexts, be comprehensive, cover all relevant sources, sinks and reservoirs of greenhouse gases and

adaptation, and comprise all economic sectors. Efforts to address climate change may be carried out cooperatively by interested Parties.

4. The Parties have a right to, and should, promote sustainable development. Policies and measures to protect the climate system against human-induced change should be appropriate for the specific conditions of each Party and should be integrated with national development programmes, taking into account that economic development is essential for adopting measures to address climate change.

5. The Parties should cooperate to promote a supportive and open international economic system that would lead to sustainable economic growth and development in all Parties, particularly developing country Parties, thus enabling them better to address the problems of climate change. Measures taken to combat climate change, including unilateral ones, should not constitute a means of arbitrary or unjustifiable discrimination or a disguised restriction on international trade.

ARTICLE 4: COMMITMENTS

1. All Parties, taking into account their common but differentiated responsibilities and their specific national and regional development priorities, objectives and circumstances, shall:

(a) Develop, periodically update, publish and make available to the Conference of the Parties, in accordance with Article 12, national inventories of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol, using comparable methodologies to be agreed upon by the Conference of the Parties;

(b) Formulate, implement, publish and regularly update national and, where appropriate, regional programmes containing measures to mitigate climate change by addressing anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol, and measures to facilitate adequate adaptation to climate change;

(c) Promote and cooperate in the development, application and diffusion, including transfer, of technologies, practices and processes that control, reduce or prevent anthropogenic emissions of greenhouse gases not controlled by the Montreal Protocol in all relevant sectors, including the energy, transport, industry, agriculture, forestry and waste management sectors;

(d) Promote sustainable management, and promote and cooperate in the conservation and enhancement, as appropriate, of sinks and reservoirs of all greenhouse gases not controlled by the Montreal Protocol, including biomass, forests and oceans as well as other terrestrial, coastal and marine ecosystems;

(e) Cooperate in preparing for adaptation to the impacts of climate change; develop and elaborate appropriate and integrated plans for coastal zone management, water resources and agriculture, and for the protection and rehabilitation of areas, particularly in Africa, affected by drought and desertification, as well as floods;

(f) Take climate change considerations into account, to the extent feasible, in their relevant social, economic and environmental policies and actions, and employ appropriate methods, for example impact assessments, formulated and determined nationally, with a view to minimizing adverse effects on the economy, on public health and on the quality of the environment, of projects or measures undertaken by them to mitigate or adapt to climate change;

(g) Promote and cooperate in scientific, technological, technical, socio-economic and other research, systematic observation and development of data archives related to the climate system and intended to further the understanding and to reduce or eliminate the remaining uncertainties regarding the causes, effects, magnitude and timing of climate change and the economic and social consequences of various response strategies;

(h) Promote and cooperate in the full, open and prompt exchange of relevant scientific, technological, technical, socio-economic and legal information related to the climate system and climate change, and to the economic and social consequences of various response strategies;

(i) Promote and cooperate in education, training and public awareness related to climate change and encourage the widest participation in this process, including that of non-governmental organizations; and

(j) Communicate to the Conference of the Parties information related to implementation, in accordance with Article 12.

2. The developed country Parties and other Parties included in Annex I commit themselves specifically as provided for in the following:

(a) Each of these Parties shall adopt national policies and take corresponding measures on the mitigation of climate change, by limiting its anthropogenic emissions of greenhouse gases and protecting and enhancing its greenhouse gas sinks and reservoirs. These policies and measures will demonstrate that developed countries are taking the lead in modifying longer-term trends in anthropogenic emissions consistent with the objective of the Convention, recognizing that the return by the end of the present decade to earlier levels of anthropogenic emissions of carbon dioxide and other greenhouse gases not controlled by the Montreal Protocol would contribute to such modification, and taking into account the differences in these Parties' starting points and approaches, economic structures and resource bases, the need to maintain strong and sustainable economic growth, available technologies and other individual circumstances, as well as the need for equitable and appropriate contributions by each of these Parties to the global effort regarding that objective. These Parties may implement such policies and measures jointly with other

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Parties and may assist other Parties in contributing to the achievement of the objective of the Convention and, in particular, that of this subparagraph;

(b) In order to promote progress to this end, each of these Parties shall communicate, within six months of the entry into force of the Convention for it and periodically thereafter, and in accordance with Article 12, detailed information on its policies and measures referred to in subparagraph (a) above, as well as on its resulting projected anthropogenic emissions by sources and removals by sinks of greenhouse gases not controlled by the Montreal Protocol for the period referred to in subparagraph (a), with the aim of returning individually or jointly to their 1990 levels these anthropogenic emissions of carbon dioxide and other greenhouse gases not controlled by the Montreal Protocol. This information will be reviewed by the Conference of the Parties, at its first session and periodically thereafter, in accordance with Article 7;

(c) Calculations of emissions by sources and removals by sinks of greenhouse gases for the purposes of subparagraph (b) above should take into account the best available scientific knowledge, including of the effective capacity of sinks and the respective contributions of such gases to climate change. The Conference of the Parties shall consider and agree on methodologies for these calculations at its first session and review them regularly thereafter;

(d) The Conference of the Parties shall, at its first session, review the adequacy of subparagraphs (a) and (b) above. Such review shall be carried out in the light of the best available scientific information and assessment on climate change and its impacts, as well as relevant technical, social and economic information. Based on this review, the Conference of the Parties shall take appropriate action, which may include the adoption of amendments to the commitments in subparagraphs (a) and (b) above. The Conference of the Parties, at its first session, shall also take decisions regarding criteria for joint implementation as indicated in subparagraph (a) above. A second review of subparagraphs (a) and (b) shall take place not later than 31 December 1998, and thereafter at regular intervals determined by the Conference of the Parties, until the objective of the Convention is met;

(e) Each of these Parties shall :

(i) Coordinate as appropriate with other such Parties, relevant economic and administrative instruments developed to achieve the objective of the Convention; and

(ii) Identify and periodically review its own policies and practices which encourage activities that lead to greater levels of anthropogenic emissions of greenhouse gases not controlled by the Montreal Protocol than would otherwise occur;

(f) The Conference of the Parties shall review, not later than 31 December 1998, available information with a view to taking decisions regarding such amendments to the lists in Annexes I and II as may be appropriate, with the approval of the Party concerned;

(g) Any Party not included in Annex I may, in its instrument of ratification, acceptance, approval or accession, or at any time thereafter, notify the Depositary that it intends to be bound by subparagraphs (a) and (b) above. The Depositary shall inform the other signatories and Parties of any such notification.

3. The developed country Parties and other developed Parties included in Annex II shall provide new and additional financial resources to meet the agreed full costs incurred by developing country Parties in complying with their obligations under Article 12, paragraph 1. They shall also provide such financial resources, including for the transfer of technology, needed by the developing country Parties to meet the agreed full incremental costs of implementing measures that are covered by paragraph 1 of this Article and that are agreed between a developing country Party and the international entity or entities referred to in Article 11, in accordance with that Article. The implementation of these commitments shall take into account the need for adequacy and predictability in the flow of funds and the importance of appropriate burden sharing among the developed country Parties.

4. The developed country Parties and other developed Parties included in Annex II shall also assist the developing country Parties that are particularly vulnerable to the adverse effects of climate change in meeting costs of adaptation to those adverse effects.

5. The developed country Parties and other developed Parties included in Annex II shall take all practicable steps to promote, facilitate and finance, as appropriate, the transfer of, or access to, environmentally sound technologies and know-how to other Parties, particularly developing country Parties, to enable them to implement the provisions of the Convention. In this process, the developed country Parties shall support the development and enhancement of endogenous capacities and technologies of developing country Parties. Other Parties and organizations in a position to do so may also assist in facilitating the transfer of such technologies.

6. In the implementation of their commitments under paragraph 2 above, a certain degree of flexibility shall be allowed by the Conference of the Parties to the Parties included in Annex I undergoing the process of transition to a market economy, in order to enhance the ability of these Parties to address climate change, including with regard to the historical level of anthropogenic emissions of greenhouse gases not controlled by the Montreal Protocol chosen as a reference.

7. The extent to which developing country Parties will effectively implement their commitments under the Convention will depend on the effective implementation by developed country Parties of their commitments under the Convention related to financial resources and transfer of technology and will take fully into account that economic and social development and poverty eradication are the first and overriding priorities of the developing country Parties.

8. In the implementation of the commitments in this Article, the Parties shall give full consideration to what actions are necessary under the Convention, including actions related to funding, insurance and the transfer of technology, to meet the specific needs and concerns of

developing country Parties arising from the adverse effects of climate change and/or the impact of the implementation of response measures, especially on:

(a) Small island countries;

(b) Countries with low-lying coastal areas;

(c) Countries with arid and semi-arid areas, forested areas and areas liable to forest decay;

(d) Countries with areas prone to natural disasters;

(e) Countries with areas liable to drought and desertification;

(f) Countries with areas of high urban atmospheric pollution;

(g) Countries with areas with fragile ecosystems, including mountainous ecosystems;

(h) Countries whose economies are highly dependent on income generated from the production, processing and export, and/or on consumption of fossil fuels and associated energy-intensive products; and

(i) Land-locked and transit countries.

Further, the Conference of the Parties may take actions, as appropriate, with respect to this paragraph.

9. The Parties shall take full account of the specific needs and special situations of the least developed countries in their actions with regard to funding and transfer of technology.

10. The Parties shall, in accordance with Article 10, take into consideration in the implementation of the commitments of the Convention the situation of Parties, particularly developing country Parties, with economies that are vulnerable to the adverse effects of the implementation of measures to respond to climate change. This applies notably to Parties with economies that are highly dependent on income generated from the production, processing and export, and/or consumption of fossil fuels and associated energy-intensive products and/or the use of fossil fuels for which such Parties have serious difficulties in switching to alternatives.

ARTICLE 5: RESEARCH AND SYSTEMATIC OBSERVATION

In carrying out their commitments under Article 4, paragraph 1(g), the Parties shall:

(a) Support and further develop, as appropriate, international and intergovernmental programmes and networks or organizations aimed at defining, conducting, assessing and financing research, data collection and systematic observation, taking into account the need to minimize duplication of effort;

(b) Support international and intergovernmental efforts to strengthen systematic observation and national scientific and technical research capacities and capabilities, particularly in developing countries, and to promote access to, and the exchange of, data and analyses thereof obtained from areas beyond national jurisdiction; and

(c) Take into account the particular concerns and needs of developing countries and cooperate in improving their endogenous capacities and capabilities to participate in the efforts referred to in subparagraphs (a) and (b) above.

ARTICLE 6: EDUCATION, TRAINING AND PUBLIC AWARENESS

In carrying out their commitments under Article 4, paragraph 1(i), the Parties shall:

(a) Promote and facilitate at the national and, as appropriate, subregional and regional levels, and in accordance with national laws and regulations, and within their respective capacities:

(i) The development and implementation of educational and public awareness programmes on climate change and its effects;

(ii) Public access to information on climate change and its effects;

(iii) Public participation in addressing climate change and its effects and developing adequate responses; and

(iv) Training of scientific, technical and managerial personnel.

(b) Cooperate in and promote, at the international level, and, where appropriate, using existing bodies:

(i) The development and exchange of educational and public awareness material on climate change and its effects; and

(ii) The development and implementation of education and training programmes, including the strengthening of national institutions and the exchange or secondment of personnel to train experts in this field, in particular for developing countries.

ARTICLE 7: CONFERENCE OF THE PARTIES

1. A Conference of the Parties is hereby established.

2. The Conference of the Parties, as the supreme body of this Convention, shall keep under regular review the implementation of the Convention and any related legal instruments that the

Conference of the Parties may adopt, and shall make, within its mandate, the decisions necessary to promote the effective implementation of the Convention. To this end, it shall:

(a) Periodically examine the obligations of the Parties and the institutional arrangements under the Convention, in the light of the objective of the Convention, the experience gained in its implementation and the evolution of scientific and technological knowledge;

(b) Promote and facilitate the exchange of information on measures adopted by the Parties to address climate change and its effects, taking into account the differing circumstances, responsibilities and capabilities of the Parties and their respective commitments under the Convention;

(c) Facilitate, at the request of two or more Parties, the coordination of measures adopted by them to address climate change and its effects, taking into account the differing circumstances, responsibilities and capabilities of the Parties and their respective commitments under the Convention;

(d) Promote and guide, in accordance with the objective and provisions of the Convention, the development and periodic refinement of comparable methodologies, to be agreed on by the Conference of the Parties, inter alia, for preparing inventories of greenhouse gas emissions by sources and removals by sinks, and for evaluating the effectiveness of measures to limit the emissions and enhance the removals of these gases;

(e) Assess, on the basis of all information made available to it in accordance with the provisions of the Convention, the implementation of the Convention by the Parties, the overall effects of the measures taken pursuant to the Convention, in particular environmental, economic and social effects as well as their cumulative impacts and the extent to which progress towards the objective of the Convention is being achieved;

(f) Consider and adopt regular reports on the implementation of the Convention and ensure their publication;

(g) Make recommendations on any matters necessary for the implementation of the Convention;

(h) Seek to mobilize financial resources in accordance with Article 4, paragraphs 3, 4 and 5, and Article 11;

(i) Establish such subsidiary bodies as are deemed necessary for the implementation of the Convention;

(j) Review reports submitted by its subsidiary bodies and provide guidance to them;

(k) Agree upon and adopt, by consensus, rules of procedure and financial rules for itself and for any subsidiary bodies;

(l) Seek and utilize, where appropriate, the services and cooperation of, and information provided by, competent international organizations and intergovernmental and non-governmental bodies; and

(m) Exercise such other functions as are required for the achievement of the objective of the Convention as well as all other functions assigned to it under the Convention.

3. The Conference of the Parties shall, at its first session, adopt its own rules of procedure as well as those of the subsidiary bodies established by the Convention, which shall include decision-making procedures for matters not already covered by decision- making procedures stipulated in the Convention. Such procedures may include specified majorities required for the adoption of particular decisions.

4. The first session of the Conference of the Parties shall be convened by the interim secretariat referred to in Article 21 and shall take place not later than one year after the date of entry into force of the Convention. Thereafter, ordinary sessions of the Conference of the Parties shall be held every year unless otherwise decided by the Conference of the Parties.

5. Extraordinary sessions of the Conference of the Parties shall be held at such other times as may be deemed necessary by the Conference, or at the written request of any Party, provided that, within six months of the request being communicated to the Parties by the secretariat, it is supported by at least one third of the Parties.

6 The United Nations, its specialized agencies and the International Atomic Energy Agency, as well as any State member thereof or observers thereto not Party to the Convention, may be represented at sessions of the Conference of the Parties as observers. Any body or agency, whether national or international, governmental or non- governmental, which is qualified in matters covered by the Convention, and which has informed the secretariat of its wish to be represented at a session of the Conference of the Parties as an observer, may be so admitted unless at least one third of the Parties present object. The admission and participation of observers shall be subject to the rules of procedure adopted by the Conference of the Parties.

ARTICLE 8: SECRETARIAT

1. A secretariat is hereby established.

2. The functions of the secretariat shall be:

(a) To make arrangements for sessions of the Conference of the Parties and its subsidiary bodies established under the Convention and to provide them with services as required;

(b) To compile and transmit reports submitted to it;

(c) To facilitate assistance to the Parties, particularly developing country Parties, on request, in the compilation and communication of information required in accordance with the provisions of the Convention;

(d) To prepare reports on its activities and present them to the Conference of the Parties;

(e) To ensure the necessary coordination with the secretariats of other relevant international bodies;

(f) To enter, under the overall guidance of the Conference of the Parties, into such administrative and contractual arrangements as may be required for the effective discharge of its functions; and

(g) To perform the other secretariat functions specified in the Convention and in any of its protocols and such other functions as may be determined by the Conference of the Parties.

3. The Conference of the Parties, at its first session, shall designate a permanent secretariat and make arrangements for its functioning.

ARTICLE 9: SUBSIDIARY BODY FOR SCIENTIFIC AND TECHNOLOGICAL ADVICE

1. A subsidiary body for scientific and technological advice is hereby established to provide the Conference of the Parties and, as appropriate, its other subsidiary bodies with timely information and advice on scientific and technological matters relating to the Convention. This body shall be open to participation by all Parties and shall be multidisciplinary. It shall comprise government representatives competent in the relevant field of expertise It shall report regularly to the Conference of the Parties on all aspects of its work.

2. Under the guidance of the Conference of the Parties, and drawing upon existing competent international bodies, this body shall:

(a) Provide assessments of the state of scientific knowledge relating to climate change and its effects;

(b) Prepare scientific assessments on the effects of measures taken in the implementation of the Convention;

(c) Identify innovative, efficient and state-of-the-art technologies and know-how and advise on the ways and means of promoting development and/or transferring such technologies;

(d) Provide advice on scientific programmes, international cooperation in research and development related to climate change, as well as on ways and means of supporting endogenous capacity-building in developing countries, and

(e) Respond to scientific, technological and methodological questions that the Conference of the Parties and its subsidiary bodies may put to the body.

3. The functions and terms of reference of this body may be further elaborated by the Conference of the Parties.

ARTICLE 10: SUBSIDIARY BODY FOR IMPLEMENTATION

1. A subsidiary body for implementation is hereby established to assist the Conference of the Parties in the assessment and review of the effective implementation of the Convention. This body shall be open to participation by all Parties and comprise government representatives who are experts on matters related to climate change. It shall report regularly to the Conference of the Parties on all aspects of its work.

2. Under the guidance of the Conference of the Parties, this body shall:

(a) Consider the information communicated in accordance with Article 12, paragraph 1, to assess the overall aggregated effect of the steps taken by the Parties in the light of the latest scientific assessments concerning climate change;

(b) Consider the information communicated in accordance with Article 12, paragraph 2, in order to assist the Conference of the Parties in carrying out the reviews required by Article 4, paragraph 2(d); and

(c) Assist the Conference of the Parties, as appropriate, in the preparation and implementation of its decisions.

ARTICLE 11: FINANCIAL MECHANISM

1. A mechanism for the provision of financial resources on a grant or concessional basis, including for the transfer of technology, is hereby defined. It shall function under the guidance of and be accountable to the Conference of the Parties, which shall decide on its policies, programme priorities and eligibility criteria related to this Convention. Its operation shall be entrusted to one or more existing international entities.

2. The financial mechanism shall have an equitable and balanced representation of all Parties within a transparent system of governance.

3. The Conference of the Parties and the entity or entities entrusted with the operation of the financial mechanism shall agree upon arrangements to give effect to the above paragraphs, which shall include the following:

(a) Modalities to ensure that the funded projects to address climate change are in conformity with the policies, programme priorities and eligibility criteria established by the Conference of the Parties;

(b) Modalities by which a particular funding decision may be reconsidered in light of these policies, programme priorities and eligibility criteria;

(c) Provision by the entity or entities of regular reports to the Conference of the Parties on its funding operations, which is consistent with the requirement for accountability set out in paragraph 1 above; and

(d) Determination in a predictable and identifiable manner of the amount of funding necessary and available for the implementation of this Convention and the conditions under which that amount shall be periodically reviewed.

4 The Conference of the Parties shall make arrangements to implement the above-mentioned provisions at its first session, reviewing and taking into account the interim arrangements referred to in Article 21, paragraph 3, and shall decide whether these interim arrangements shall be maintained. Within four years thereafter, the Conference of the Parties shall review the financial mechanism and take appropriate measures.

5. The developed country Parties may also provide and developing country Parties avail themselves of, financial resources related to the implementation of the Convention through bilateral, regional and other multilateral channels.

ARTICLE 12: COMMUNICATION OF INFORMATION RELATED TO IMPLEMENTATION

1 In accordance with Article 4, paragraph 1, each Party shall communicate to the Conference of the Parties, through the secretariat, the following elements of information:

(a) A national inventory of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol, to the extent its capacities permit, using comparable methodologies to be promoted and agreed upon by the Conference of the Parties;

(b) A general description of steps taken or envisaged by the Party to implement the Convention; and

(c) Any other information that the Party considers relevant to the achievement of the objective of the Convention and suitable for inclusion in its communication, including, if feasible, material relevant for calculations of global emission trends.

2. Each developed country Party and each other Party included in Annex I shall incorporate in its communication the following elements of information:

(a) A detailed description of the policies and measures that it has adopted to implement its commitment under Article 4, paragraphs 2(a) and 2(b), and

(b) A specific estimate of the effects that the policies and measures referred to in subparagraph (a) immediately above will have on anthropogenic emissions by its sources and removals by its sinks of greenhouse gases during the period referred to in Article 4, paragraph 2(a).

3. In addition, each developed country Party and each other developed Party included in Annex II shall incorporate details of measures taken in accordance with Article 4, paragraphs 3, 4 and 5.

4. Developing country Parties may, on a voluntary basis, propose projects for financing, including specific technologies, materials, equipment, techniques or practices that would be needed to implement such projects, along with, if possible, an estimate of all incremental costs, of the reductions of emissions and increments of removals of greenhouse gases, as well as an estimate of the consequent benefits.

5. Each developed country Party and each other Party included in Annex I shall make its initial communication within six months of the entry into force of the Convention for that Party. Each Party not so listed shall make its initial communication within three years of the entry into force of the Convention for that Party, or of the availability of financial resources in accordance with Article 4, paragraph 3. Parties that are least developed countries may make their initial communication at their discretion. The frequency of subsequent communications by all Parties shall be determined by the Conference of the Parties, taking into account the differentiated timetable set by this paragraph.

6. Information communicated by Parties under this Article shall be transmitted by the secretariat as soon as possible to the Conference of the Parties and to any subsidiary bodies concerned. If necessary, the procedures for the communication of information may be further considered by the Conference of the Parties.

7. From its first session, the Conference of the Parties shall arrange for the provision to developing country Parties of technical and financial support, on request, in compiling and communicating information under this Article, as well as in identifying the technical and financial needs associated with proposed projects and response measures under Article 4. Such support may be provided by other Parties, by competent international organizations and by the secretariat, as appropriate

8 Any group of Parties may, subject to guidelines adopted by the Conference of the Parties, and to prior notification to the Conference of the Parties, make a joint communication in fulfilment of their obligations under this Article, provided that such a communication includes information on the fulfilment by each of these Parties of its individual obligations under the Convention.

9. Information received by the secretariat that is designated by a Party as confidential, in accordance with criteria to be established by the Conference of the Parties, shall be aggregated by the secretariat to protect its confidentiality before being made available to any of the bodies involved in the communication and review of information.

10. Subject to paragraph 9 above, and without prejudice to the ability of any Party to make public its communication at any time, the secretariat shall make communications by Parties under this Article publicly available at the time they are submitted to the Conference of the Parties.

ARTICLE 13: RESOLUTION OF QUESTIONS REGARDING IMPLEMENTATION

The Conference of the Parties shall, at its first session, consider the establishment of a multilateral consultative process, available to Parties on their request, for the resolution of questions regarding the implementation of the Convention.

ARTICLE 14: SETTLEMENT OF DISPUTES

1. In the event of a dispute between any two or more Parties concerning the interpretation or application of the Convention, the Parties concerned shall seek a settlement of the dispute through negotiation or any other peaceful means of their own choice.

2. When ratifying, accepting, approving or acceding to the Convention, or at any time thereafter, a Party which is not a regional economic integration organization may declare in a written instrument submitted to the Depositary that, in respect of any dispute concerning the interpretation or application of the Convention, it recognizes as compulsory ipso facto and without special agreement, in relation to any Party accepting the same obligation:

(a) Submission of the dispute to the International Court of Justice, and/or

(b) Arbitration in accordance with procedures to be adopted by the Conference of the Parties as soon as practicable, in an annex on arbitration.

A Party which is a regional economic integration organization may make a declaration with like effect in relation to arbitration in accordance with the procedures referred to in subparagraph (b) above.

3. A declaration made under paragraph 2 above shall remain in force until it expires in accordance with its terms or until three months after written notice of its revocation has been deposited with the Depositary.

4. A new declaration, a notice of revocation or the expiry of a declaration shall not in any way affect proceedings pending before the International Court of Justice or the arbitral tribunal, unless the parties to the dispute otherwise agree.

5. Subject to the operation of paragraph 2 above, if after twelve months following notification by one Party to another that a dispute exists between them, the Parties concerned have not been able to settle their dispute through the means mentioned in paragraph 1 above, the dispute shall be submitted, at the request of any of the parties to the dispute, to conciliation.

6. A conciliation commission shall be created upon the request of one of the parties to the dispute. The commission shall be composed of an equal number of members appointed by each party concerned and a chairman chosen jointly by the members appointed by each party. The commission shall render a recommendatory award, which the parties shall consider in good faith.

7. Additional procedures relating to conciliation shall be adopted by the Conference of the Parties, as soon as practicable, in an annex on conciliation.

8. The provisions of this Article shall apply to any related legal instrument which the Conference of the Parties may adopt, unless the instrument provides otherwise.

ARTICLE 15: AMENDMENTS TO THE CONVENTION

1. Any Party may propose amendments to the Convention.

2. Amendments to the Convention shall be adopted at an ordinary session of the Conference of the Parties. The text of any proposed amendment to the Convention shall be communicated to the Parties by the secretariat at least six months before the meeting at which it is proposed for adoption. The secretariat shall also communicate proposed amendments to the signatories to the Convention and, for information, to the Depositary.

3. The Parties shall make every effort to reach agreement on any proposed amendment to the Convention by consensus. If all efforts at consensus have been exhausted, and no agreement reached, the amendment shall as a last resort be adopted by a three-fourths majority vote of the Parties present and voting at the meeting. The adopted amendment shall be communicated by the secretariat to the Depositary, who shall circulate it to all Parties for their acceptance.

4. Instruments of acceptance in respect of an amendment shall be deposited with the Depositary. An amendment adopted in accordance with paragraph 3 above shall enter into force for those Parties having accepted it on the ninetieth day after the date of receipt by the Depositary of an instrument of acceptance by at least three fourths of the Parties to the Convention.

5. The amendment shall enter into force for any other Party on the ninetieth day after the date on which that Party deposits with the Depositary its instrument of acceptance of the said amendment.

6. For the purposes of this Article, "Parties present and voting" means Parties present and casting an affirmative or negative vote.

ARTICLE 16: ADOPTION AND AMENDMENT OF ANNEXES TO THE CONVENTION

1. Annexes to the Convention shall form an integral part thereof and, unless otherwise expressly provided, a reference to the Convention constitutes at the same time a reference to any annexes thereto. Without prejudice to the provisions of Article 14, paragraphs 2(b) and 7, such annexes

shall be restricted to lists, forms and any other material of a descriptive nature that is of a scientific, technical, procedural or administrative character.

2. Annexes to the Convention shall be proposed and adopted in accordance with the procedure set forth in Article 15, paragraphs 2, 3 and 4.

3. An annex that has been adopted in accordance with paragraph 2 above shall enter into force for all Parties to the Convention six months after the date of the communication by the Depositary to such Parties of the adoption of the annex, except for those Parties that have notified the Depositary, in writing, within that period of their non-acceptance of the annex. The annex shall enter into force for Parties which withdraw their notification of non-acceptance on the ninetieth day after the date on which withdrawal of such notification has been received by the Depositary.

4. The proposal, adoption and entry into force of amendments to annexes to the Convention shall be subject to the same procedure as that for the proposal, adoption and entry into force of annexes to the Convention in accordance with paragraphs 2 and 3 above.

5. If the adoption of an annex or an amendment to an annex involves an amendment to the Convention, that annex or amendment to an annex shall not enter into force until such time as the amendment to the Convention enters into force.

ARTICLE 17: PROTOCOLS

1. The Conference of the Parties may, at any ordinary session, adopt protocols to the Convention.

2. The text of any proposed protocol shall be communicated to the Parties by the secretariat at least six months before such a session.

3. The requirements for the entry into force of any protocol shall be established by that instrument.

4. Only Parties to the Convention may be Parties to a protocol.

5. Decisions under any protocol shall be taken only by the Parties to the protocol concerned

ARTICLE 18: RIGHT TO VOTE

1. Each Party to the Convention shall have one vote, except as provided for in paragraph 2 below

2. Regional economic integration organizations, in matters within their competence, shall exercise their right to vote with a number of votes equal to the number of their member States that are Parties to the Convention. Such an organization shall not exercise its right to vote if any of its member States exercises its right, and vice versa

ARTICLE 19: DEPOSITARY

The Secretary-General of the United Nations shall be the Depositary of the Convention and of protocols adopted in accordance with Article 17.

ARTICLE 20: SIGNATURE

This Convention shall be open for signature by States Members of the United Nations or of any of its specialized agencies or that are Parties to the Statute of the International Court of Justice and by regional economic integration organizations at Rio de Janeiro, during the United Nations Conference on Environment and Development, and thereafter at United Nations Headquarters in New York from 20 June 1992 to 19 June 1993.

ARTICLE 21: INTERIM ARRANGEMENTS

1. The secretariat functions referred to in Article 8 will be carried out on an interim basis by the secretariat established by the General Assembly of the United Nations in its resolution 45/212 of 21 December 1990, until the completion of the first session of the Conference of the Parties.

2. The head of the interim secretariat referred to in paragraph 1 above will cooperate closely with the Intergovernmental Panel on Climate Change to ensure that the Panel can respond to the need for objective scientific and technical advice. Other relevant scientific bodies could also be consulted.

3. The Global Environment Facility of the United Nations Development Programme, the United Nations Environment Programme and the International Bank for Reconstruction and Development shall be the international entity entrusted with the operation of the financial mechanism referred to in Article 11 on an interim basis. In this connection, the Global Environment Facility should be appropriately restructured and its membership made universal to enable it to fulfil the requirements of Article 11.

ARTICLE 22: RATIFICATION, ACCEPTANCE, APPROVAL OR ACCESSION

1 The Convention shall be subject to ratification, acceptance, approval or accession by States and by regional economic integration organizations. It shall be open for accession from the day after the date on which the Convention is closed for signature. Instruments of ratification, acceptance, approval or accession shall be deposited with the Depositary.

2. Any regional economic integration organization which becomes a Party to the Convention without any of its member States being a Party shall be bound by all the obligations under the Convention. In the case of such organizations, one or more of whose member States is a Party to the Convention, the organization and its member States shall decide on their respective responsibilities for the performance of their obligations under the Convention. In such cases, the

organization and the member States shall not be entitled to exercise rights under the Convention concurrently.

3. In their instruments of ratification, acceptance, approval or accession, regional economic integration organizations shall declare the extent of their competence with respect to the matters governed by the Convention. These organizations shall also inform the Depositary, who shall in turn inform the Parties, of any substantial modification in the extent of their competence.

ARTICLE 23: ENTRY INTO FORCE

1. The Convention shall enter into force on the ninetieth day after the date of deposit of the fiftieth instrument of ratification, acceptance, approval or accession.

2. For each State or regional economic integration organization that ratifies, accepts or approves the Convention or accedes thereto after the deposit of the fiftieth instrument of ratification, acceptance, approval or accession, the Convention shall enter into force on the ninetieth day after the date of deposit by such State or regional economic integration organization of its instrument of ratification, acceptance, approval or accession.

3. For the purposes of paragraphs 1 and 2 above, any instrument deposited by a regional economic integration organization shall not be counted as additional to those deposited by States members of the organization.

ARTICLE 24: RESERVATIONS

No reservations may be made to the Convention.

ARTICLE 25: WITHDRAWAL

1. At any time after three years from the date on which the Convention has entered into force for a Party, that Party may withdraw from the Convention by giving written notification to the Depositary.

2. Any such withdrawal shall take effect upon expiry of one year from the date of receipt by the Depositary of the notification of withdrawal, or on such later date as may bespecified in the notification of withdrawal.

3. Any Party that withdraws from the Convention shall be considered as also having withdrawn from any protocol to which it is a Party.

ARTICLE 26: AUTHENTIC TEXTS

The original of this Convention, of which the Arabic, Chinese, English, French, Russian and Spanish texts are equally authentic, shall be deposited with the Secretary- General of the United Nations.

IN WITNESS WHEREOF the undersigned, being duly authorized to that effect, have signed this Convention.

DONE at New York this ninth day of May one thousand nine hundred and ninety-two.

ANNEX I

Australia
Austria
Belarus[a/]
Belgium
Bulgaria[a/]
Canada
Crotia[a/]
Czech Republic[a/]
Denmark
European Economic Community
Estonia[a/]
Finland
France
Germany
Greece
Hungary[a/]
Iceland
Ireland
Italy
Japan
Latvia[a/]
Liechtenstein
Lithuania[a/]
Luxembourg
Monaco
Netherlands
New Zealand
Norway
Poland[a/]
Portugal
Romania[a/]
Russian Federation[a/]
Slovakia[a/]
Slovenia[a/]
Spain
Sweden
Switzerland
Turkey
Ukraine[a/]
United Kingdom of Great Britain and Northern Ireland
United States of America

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[a] Countries that are undergoing the process of transition to a market economy.

Annex II

Australia
Austria
Belgium
Canada
Denmark
European Economic Community
Finland
France
Germany
Greece
Iceland
Ireland
Italy
Japan
Luxembourg
Netherlands
New Zealand
Norway
Portugal
Spain
Sweden
Switzerland
Turkey
United Kingdom of Great Britain and Northern Ireland
United States of America

UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE

The Parties to this Convention,

Acknowledging that change in the Earth's climate and its adverse effects are a common concern of humankind,

Concerned that human activities have been substantially increasing the atmospheric concentrations of greenhouse gases, that these increases enhance the natural greenhouse effect, and that this will result on average in an additional warming of the Earth's surface and atmosphere and may adversely affect natural ecosystems and humankind,

Noting that the largest share of historical and current global emissions of greenhouse gases has originated in developed countries, that per capita emissions in developing countries are still relatively low and that the share of global emissions originating in developing countries will grow to meet their social and development needs,

Aware of the role and importance in terrestrial and marine ecosystems of sinks and reservoirs of greenhouse gases,

Noting that there are many uncertainties in predictions of climate change, particularly with regard to the timing, magnitude and regional patterns thereof,

Acknowledging that the global nature of climate change calls for the widest possible cooperation by all countries and their participation in an effective and appropriate international response, in accordance with their common but differentiated responsibilities and respective capabilities and their social and economic conditions,

Recalling the pertinent provisions of the Declaration of the United Nations Conference on the Human Environment, adopted at Stockholm on 16 June 1972,

Recalling also that States have, in accordance with the Charter of the United Nations and the principles of international law, the sovereign right to exploit their own resources pursuant to their own environmental and developmental policies, and the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction,

Reaffirming the principle of sovereignty of States in international cooperation to address climate change,

Recognizing that States should enact effective environmental legislation, that environmental standards, management objectives and priorities should reflect the environmental and developmental context to which they apply, and that standards applied by some countries may be inappropriate and of unwarranted economic and social cost to other countries, in particular developing countries, Recalling the provisions of General Assembly resolution 44/228 of 22 December 1989 on the United Nations Conference on Environment and Development, and resolutions 43/53 of 6 December 1988, 44/207 of 22 December 1989, 45/212 of 21 December 1990 and 46/169 of 19 December 1991 on protection of global climate for present and future generations of mankind,

Recalling also the provisions of General Assembly resolution 44/206 of 22 December 1989 on the possible adverse effects of sea-level rise on islands and coastal areas, particularly low-lying coastal areas and the pertinent provisions of General Assembly resolution 44/172 of 19 December 1989 on the implementation of the Plan of Action to Combat Desertification,

Recalling further the Vienna Convention for the Protection of the Ozone Layer, 1985, and the Montreal Protocol on Substances that Deplete the Ozone Layer, 1987, as adjusted and amended on 29 June 1990,

Noting the Ministerial Declaration of the Second World Climate Conference adopted on 7 November 1990,

Conscious of the valuable analytical work being conducted by many States on climate change and of the important contributions of the World Meteorological Organization, the United Nations Environment Programme and other organs, organizations and bodies of the United Nations system, as well as other international and intergovernmental bodies, to the exchange of results of scientific research and the coordination of research,

Recognizing that steps required to understand and address climate change will be environmentally, socially and economically most effective if they are based on relevant scientific, technical and economic considerations and continually re-evaluated in the light of new findings in these areas,

Recognizing that various actions to address climate change can be justified economically in their own right and can also help in solving other environmental problems,

Recognizing also the need for developed countries to take immediate action in a flexible manner on the basis of clear priorities, as a first step towards comprehensive response strategies at the global, national and, where agreed, regional levels that take into account all greenhouse gases, with due consideration of their relative contributions to the enhancement of the greenhouse effect,

Recognizing further that low-lying and other small island countries, countries with low-lying coastal, arid and semi-arid areas or areas liable to floods, drought and desertification, and developing countries with fragile mountainous ecosystems are particularly vulnerable to the adverse effects of climate change, Recognizing the special difficulties of those countries, especially developing countries, whose economies are particularly dependent on fossil fuel production, use and exportation, as a consequence of action taken on limiting greenhouse gas emissions,

Affirming that responses to climate change should be coordinated with social and economic development in an integrated manner with a view to avoiding adverse impacts on the latter, taking into full account the legitimate priority needs of developing countries for the achievement of sustained economic growth and the eradication of poverty,

Recognizing that all countries, especially developing countries, need access to resources required to achieve sustainable social and economic development and that, in order for developing countries to progress towards that goal, their energy consumption will need to grow taking into account the possibilities for achieving greater energy efficiency and for controlling greenhouse gas emissions in general, including through the application of new technologies on terms which make such an application economically and socially beneficial,

Determined to protect the climate system for present and future generations,

Have agreed as follows:

ARTICLE 1: DEFINITIONS*

For the purposes of this Convention:

1. "Adverse effects of climate change" means changes in the physical environment or biota resulting from climate change which have significant deleterious effects on the composition, resilience or productivity of natural and managed ecosystems or on the operation of socio-economic systems or on human health and welfare.

2. "Climate change" means a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.

3. "Climate system" means the totality of the atmosphere, hydrosphere, biosphere and geosphere and their interactions.

4. "Emissions" means the release of greenhouse gases and/or their precursors into the atmosphere over a specified area and period of time.

5. "Greenhouse gases" means those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and re-emit infrared radiation.

6 "Regional economic integration organization" means an organization constituted by sovereign States of a given region which has competence in respect of matters governed by this Convention

*Titles of articles are included solely to assist the reader or its protocols and has been duly authorized, in accordance with its internal procedures, to sign, ratify, accept, approve or accede to the instruments concerned.

7. "Reservoir" means a component or components of the climate system where a greenhouse gas or a precursor of a greenhouse gas is stored.

8. "Sink" means any process, activity or mechanism which removes a greenhouse gas, an aerosol or a precursor of a greenhouse gas from the atmosphere.

9. "Source" means any process or activity which releases a greenhouse gas, an aerosol or a precursor of a greenhouse gas into the atmosphere.

ARTICLE 2: OBJECTIVE

The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.

ARTICLE 3: PRINCIPLES

In their actions to achieve the objective of the Convention and to implement its provisions, the Parties shall be guided, inter alia, by the following:

1. The Parties should protect the climate system for the benefit of present and future generations of humankind, on the basis of equity and in accordance with their common but differentiated responsibilities and respective capabilities Accordingly, the developed country Parties should take the lead in combating climate change and the adverse effects thereof.

2. The specific needs and special circumstances of developing country Parties, especially those that are particularly vulnerable to the adverse effects of climate change, and of those Parties, especially developing country Parties, that would have to bear a disproportionate or abnormal burden under the Convention, should be given full consideration

3 The Parties should take precautionary measures to anticipate, prevent or minimize the causes of climate change and mitigate its adverse effects. Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing such measures, taking into account that policies and measures to deal with climate change should be cost-effective so as to ensure global benefits at the lowest possible cost. To achieve this, such policies and measures should take into account different socio-economic contexts, be comprehensive, cover all relevant sources, sinks and reservoirs of greenhouse gases and

adaptation, and comprise all economic sectors. Efforts to address climate change may be carried out cooperatively by interested Parties.

4. The Parties have a right to, and should, promote sustainable development. Policies and measures to protect the climate system against human-induced change should be appropriate for the specific conditions of each Party and should be integrated with national development programmes, taking into account that economic development is essential for adopting measures to address climate change.

5. The Parties should cooperate to promote a supportive and open international economic system that would lead to sustainable economic growth and development in all Parties, particularly developing country Parties, thus enabling them better to address the problems of climate change. Measures taken to combat climate change, including unilateral ones, should not constitute a means of arbitrary or unjustifiable discrimination or a disguised restriction on international trade.

ARTICLE 4: COMMITMENTS

1. All Parties, taking into account their common but differentiated responsibilities and their specific national and regional development priorities, objectives and circumstances, shall:

(a) Develop, periodically update, publish and make available to the Conference of the Parties, in accordance with Article 12, national inventories of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol, using comparable methodologies to be agreed upon by the Conference of the Parties;

(b) Formulate, implement, publish and regularly update national and, where appropriate, regional programmes containing measures to mitigate climate change by addressing anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol, and measures to facilitate adequate adaptation to climate change;

(c) Promote and cooperate in the development, application and diffusion, including transfer, of technologies, practices and processes that control, reduce or prevent anthropogenic emissions of greenhouse gases not controlled by the Montreal Protocol in all relevant sectors, including the energy, transport, industry, agriculture, forestry and waste management sectors;

(d) Promote sustainable management, and promote and cooperate in the conservation and enhancement, as appropriate, of sinks and reservoirs of all greenhouse gases not controlled by the Montreal Protocol, including biomass, forests and oceans as well as other terrestrial, coastal and marine ecosystems;

(e) Cooperate in preparing for adaptation to the impacts of climate change; develop and elaborate appropriate and integrated plans for coastal zone management, water resources and agriculture, and for the protection and rehabilitation of areas, particularly in Africa, affected by drought and desertification, as well as floods;

(f) Take climate change considerations into account, to the extent feasible, in their relevant social, economic and environmental policies and actions, and employ appropriate methods, for example impact assessments, formulated and determined nationally, with a view to minimizing adverse effects on the economy, on public health and on the quality of the environment, of projects or measures undertaken by them to mitigate or adapt to climate change;

(g) Promote and cooperate in scientific, technological, technical, socio-economic and other research, systematic observation and development of data archives related to the climate system and intended to further the understanding and to reduce or eliminate the remaining uncertainties regarding the causes, effects, magnitude and timing of climate change and the economic and social consequences of various response strategies;

(h) Promote and cooperate in the full, open and prompt exchange of relevant scientific, technological, technical, socio-economic and legal information related to the climate system and climate change, and to the economic and social consequences of various response strategies;

(i) Promote and cooperate in education, training and public awareness related to climate change and encourage the widest participation in this process, including that of non-governmental organizations; and

(j) Communicate to the Conference of the Parties information related to implementation, in accordance with Article 12.

2. The developed country Parties and other Parties included in Annex I commit themselves specifically as provided for in the following:

(a) Each of these Parties shall adopt national policies and take corresponding measures on the mitigation of climate change, by limiting its anthropogenic emissions of greenhouse gases and protecting and enhancing its greenhouse gas sinks and reservoirs. These policies and measures will demonstrate that developed countries are taking the lead in modifying longer-term trends in anthropogenic emissions consistent with the objective of the Convention, recognizing that the return by the end of the present decade to earlier levels of anthropogenic emissions of carbon dioxide and other greenhouse gases not controlled by the Montreal Protocol would contribute to such modification, and taking into account the differences in these Parties' starting points and approaches, economic structures and resource bases, the need to maintain strong and sustainable economic growth, available technologies and other individual circumstances, as well as the need for equitable and appropriate contributions by each of these Parties to the global effort regarding that objective. These Parties may implement such policies and measures jointly with other

Parties and may assist other Parties in contributing to the achievement of the objective of the Convention and, in particular, that of this subparagraph;

(b) In order to promote progress to this end, each of these Parties shall communicate, within six months of the entry into force of the Convention for it and periodically thereafter, and in accordance with Article 12, detailed information on its policies and measures referred to in subparagraph (a) above, as well as on its resulting projected anthropogenic emissions by sources and removals by sinks of greenhouse gases not controlled by the Montreal Protocol for the period referred to in subparagraph (a), with the aim of returning individually or jointly to their 1990 levels these anthropogenic emissions of carbon dioxide and other greenhouse gases not controlled by the Montreal Protocol. This information will be reviewed by the Conference of the Parties, at its first session and periodically thereafter, in accordance with Article 7;

(c) Calculations of emissions by sources and removals by sinks of greenhouse gases for the purposes of subparagraph (b) above should take into account the best available scientific knowledge, including of the effective capacity of sinks and the respective contributions of such gases to climate change The Conference of the Parties shall consider and agree on methodologies for these calculations at its first session and review them regularly thereafter;

(d) The Conference of the Parties shall, at its first session, review the adequacy of subparagraphs (a) and (b) above. Such review shall be carried out in the light of the best available scientific information and assessment on climate change and its impacts, as well as relevant technical, social and economic information. Based on this review, the Conference of the Parties shall take appropriate action, which may include the adoption of amendments to the commitments in subparagraphs (a) and (b) above. The Conference of the Parties, at its first session, shall also take decisions regarding criteria for joint implementation as indicated in subparagraph (a) above. A second review of subparagraphs (a) and (b) shall take place not later than 31 December 1998, and thereafter at regular intervals determined by the Conference of the Parties, until the objective of the Convention is met;

(e) Each of these Parties shall :

(i) Coordinate as appropriate with other such Parties, relevant economic and administrative instruments developed to achieve the objective of the Convention; and

(ii) Identify and periodically review its own policies and practices which encourage activities that lead to greater levels of anthropogenic emissions of greenhouse gases not controlled by the Montreal Protocol than would otherwise occur;

(f) The Conference of the Parties shall review, not later than 31 December 1998, available information with a view to taking decisions regarding such amendments to the lists in Annexes I and II as may be appropriate, with the approval of the Party concerned;

(g) Any Party not included in Annex I may, in its instrument of ratification, acceptance, approval or accession, or at any time thereafter, notify the Depositary that it intends to be bound by subparagraphs (a) and (b) above. The Depositary shall inform the other signatories and Parties of any such notification.

3. The developed country Parties and other developed Parties included in Annex II shall provide new and additional financial resources to meet the agreed full costs incurred by developing country Parties in complying with their obligations under Article 12, paragraph 1. They shall also provide such financial resources, including for the transfer of technology, needed by the developing country Parties to meet the agreed full incremental costs of implementing measures that are covered by paragraph 1 of this Article and that are agreed between a developing country Party and the international entity or entities referred to in Article 11, in accordance with that Article. The implementation of these commitments shall take into account the need for adequacy and predictability in the flow of funds and the importance of appropriate burden sharing among the developed country Parties.

4. The developed country Parties and other developed Parties included in Annex II shall also assist the developing country Parties that are particularly vulnerable to the adverse effects of climate change in meeting costs of adaptation to those adverse effects.

5. The developed country Parties and other developed Parties included in Annex II shall take all practicable steps to promote, facilitate and finance, as appropriate, the transfer of, or access to, environmentally sound technologies and know-how to other Parties, particularly developing country Parties, to enable them to implement the provisions of the Convention. In this process, the developed country Parties shall support the development and enhancement of endogenous capacities and technologies of developing country Parties Other Parties and organizations in a position to do so may also assist in facilitating the transfer of such technologies.

6. In the implementation of their commitments under paragraph 2 above, a certain degree of flexibility shall be allowed by the Conference of the Parties to the Parties included in Annex I undergoing the process of transition to a market economy, in order to enhance the ability of these Parties to address climate change, including with regard to the historical level of anthropogenic emissions of greenhouse gases not controlled by the Montreal Protocol chosen as a reference.

7. The extent to which developing country Parties will effectively implement their commitments under the Convention will depend on the effective implementation by developed country Parties of their commitments under the Convention related to financial resources and transfer of technology and will take fully into account that economic and social development and poverty eradication are the first and overriding priorities of the developing country Parties.

8. In the implementation of the commitments in this Article, the Parties shall give full consideration to what actions are necessary under the Convention, including actions related to funding, insurance and the transfer of technology, to meet the specific needs and concerns of

developing country Parties arising from the adverse effects of climate change and/or the impact of the implementation of response measures, especially on:

(a) Small island countries;

(b) Countries with low-lying coastal areas;

(c) Countries with arid and semi-arid areas, forested areas and areas liable to forest decay;

(d) Countries with areas prone to natural disasters;

(e) Countries with areas liable to drought and desertification;

(f) Countries with areas of high urban atmospheric pollution;

(g) Countries with areas with fragile ecosystems, including mountainous ecosystems;

(h) Countries whose economies are highly dependent on income generated from the production, processing and export, and/or on consumption of fossil fuels and associated energy-intensive products; and

(i) Land-locked and transit countries.

Further, the Conference of the Parties may take actions, as appropriate, with respect to this paragraph.

9. The Parties shall take full account of the specific needs and special situations of the least developed countries in their actions with regard to funding and transfer of technology.

10. The Parties shall, in accordance with Article 10, take into consideration in the implementation of the commitments of the Convention the situation of Parties, particularly developing country Parties, with economies that are vulnerable to the adverse effects of the implementation of measures to respond to climate change. This applies notably to Parties with economies that are highly dependent on income generated from the production, processing and export, and/or consumption of fossil fuels and associated energy-intensive products and/or the use of fossil fuels for which such Parties have serious difficulties in switching to alternatives.

ARTICLE 5: RESEARCH AND SYSTEMATIC OBSERVATION

In carrying out their commitments under Article 4, paragraph 1(g), the Parties shall:

(a) Support and further develop, as appropriate, international and intergovernmental programmes and networks or organizations aimed at defining, conducting, assessing and financing research, data collection and systematic observation, taking into account the need to minimize duplication of effort;

(b) Support international and intergovernmental efforts to strengthen systematic observation and national scientific and technical research capacities and capabilities, particularly in developing countries, and to promote access to, and the exchange of, data and analyses thereof obtained from areas beyond national jurisdiction; and

(c) Take into account the particular concerns and needs of developing countries and cooperate in improving their endogenous capacities and capabilities to participate in the efforts referred to in subparagraphs (a) and (b) above.

ARTICLE 6: EDUCATION, TRAINING AND PUBLIC AWARENESS

In carrying out their commitments under Article 4, paragraph 1(i), the Parties shall:

(a) Promote and facilitate at the national and, as appropriate, subregional and regional levels, and in accordance with national laws and regulations, and within their respective capacities:

(i) The development and implementation of educational and public awareness programmes on climate change and its effects;

(ii) Public access to information on climate change and its effects;

(iii) Public participation in addressing climate change and its effects and developing adequate responses; and

(iv) Training of scientific, technical and managerial personnel.

(b) Cooperate in and promote, at the international level, and, where appropriate, using existing bodies:

(i) The development and exchange of educational and public awareness material on climate change and its effects; and

(ii) The development and implementation of education and training programmes, including the strengthening of national institutions and the exchange or secondment of personnel to train experts in this field, in particular for developing countries.

ARTICLE 7: CONFERENCE OF THE PARTIES

1 A Conference of the Parties is hereby established.

2 The Conference of the Parties, as the supreme body of this Convention, shall keep under regular review the implementation of the Convention and any related legal instruments that the

Conference of the Parties may adopt, and shall make, within its mandate, the decisions necessary to promote the effective implementation of the Convention. To this end, it shall:

(a) Periodically examine the obligations of the Parties and the institutional arrangements under the Convention, in the light of the objective of the Convention, the experience gained in its implementation and the evolution of scientific and technological knowledge;

(b) Promote and facilitate the exchange of information on measures adopted by the Parties to address climate change and its effects, taking into account the differing circumstances, responsibilities and capabilities of the Parties and their respective commitments under the Convention;

(c) Facilitate, at the request of two or more Parties, the coordination of measures adopted by them to address climate change and its effects, taking into account the differing circumstances, responsibilities and capabilities of the Parties and their respective commitments under the Convention;

(d) Promote and guide, in accordance with the objective and provisions of the Convention, the development and periodic refinement of comparable methodologies, to be agreed on by the Conference of the Parties, inter alia, for preparing inventories of greenhouse gas emissions by sources and removals by sinks, and for evaluating the effectiveness of measures to limit the emissions and enhance the removals of these gases;

(e) Assess, on the basis of all information made available to it in accordance with the provisions of the Convention, the implementation of the Convention by the Parties, the overall effects of the measures taken pursuant to the Convention, in particular environmental, economic and social effects as well as their cumulative impacts and the extent to which progress towards the objective of the Convention is being achieved;

(f) Consider and adopt regular reports on the implementation of the Convention and ensure their publication;

(g) Make recommendations on any matters necessary for the implementation of the Convention;

(h) Seek to mobilize financial resources in accordance with Article 4, paragraphs 3, 4 and 5, and Article 11;

(i) Establish such subsidiary bodies as are deemed necessary for the implementation of the Convention;

(j) Review reports submitted by its subsidiary bodies and provide guidance to them;

(k) Agree upon and adopt, by consensus, rules of procedure and financial rules for itself and for any subsidiary bodies,

(l) Seek and utilize, where appropriate, the services and cooperation of, and information provided by, competent international organizations and intergovernmental and non-governmental bodies; and

(m) Exercise such other functions as are required for the achievement of the objective of the Convention as well as all other functions assigned to it under the Convention.

3. The Conference of the Parties shall, at its first session, adopt its own rules of procedure as well as those of the subsidiary bodies established by the Convention, which shall include decision-making procedures for matters not already covered by decision- making procedures stipulated in the Convention. Such procedures may include specified majorities required for the adoption of particular decisions.

4. The first session of the Conference of the Parties shall be convened by the interim secretariat referred to in Article 21 and shall take place not later than one year after the date of entry into force of the Convention. Thereafter, ordinary sessions of the Conference of the Parties shall be held every year unless otherwise decided by the Conference of the Parties.

5. Extraordinary sessions of the Conference of the Parties shall be held at such other times as may be deemed necessary by the Conference, or at the written request of any Party, provided that, within six months of the request being communicated to the Parties by the secretariat, it is supported by at least one third of the Parties.

6. The United Nations, its specialized agencies and the International Atomic Energy Agency, as well as any State member thereof or observers thereto not Party to the Convention, may be represented at sessions of the Conference of the Parties as observers. Any body or agency, whether national or international, governmental or non- governmental, which is qualified in matters covered by the Convention, and which has informed the secretariat of its wish to be represented at a session of the Conference of the Parties as an observer, may be so admitted unless at least one third of the Parties present object. The admission and participation of observers shall be subject to the rules of procedure adopted by the Conference of the Parties.

ARTICLE 8: SECRETARIAT

1. A secretariat is hereby established.

2 The functions of the secretariat shall be:

(a) To make arrangements for sessions of the Conference of the Parties and its subsidiary bodies established under the Convention and to provide them with services as required;

(b) To compile and transmit reports submitted to it;

(c) To facilitate assistance to the Parties, particularly developing country Parties, on request, in the compilation and communication of information required in accordance with the provisions of the Convention;

(d) To prepare reports on its activities and present them to the Conference of the Parties;

(e) To ensure the necessary coordination with the secretariats of other relevant international bodies;

(f) To enter, under the overall guidance of the Conference of the Parties, into such administrative and contractual arrangements as may be required for the effective discharge of its functions; and

(g) To perform the other secretariat functions specified in the Convention and in any of its protocols and such other functions as may be determined by the Conference of the Parties.

3. The Conference of the Parties, at its first session, shall designate a permanent secretariat and make arrangements for its functioning.

ARTICLE 9: SUBSIDIARY BODY FOR SCIENTIFIC AND TECHNOLOGICAL ADVICE

1. A subsidiary body for scientific and technological advice is hereby established to provide the Conference of the Parties and, as appropriate, its other subsidiary bodies with timely information and advice on scientific and technological matters relating to the Convention. This body shall be open to participation by all Parties and shall be multidisciplinary. It shall comprise government representatives competent in the relevant field of expertise. It shall report regularly to the Conference of the Parties on all aspects of its work.

2. Under the guidance of the Conference of the Parties, and drawing upon existing competent international bodies, this body shall:

(a) Provide assessments of the state of scientific knowledge relating to climate change and its effects;

(b) Prepare scientific assessments on the effects of measures taken in the implementation of the Convention;

(c) Identify innovative, efficient and state-of-the-art technologies and know-how and advise on the ways and means of promoting development and/or transferring such technologies;

(d) Provide advice on scientific programmes, international cooperation in research and development related to climate change, as well as on ways and means of supporting endogenous capacity-building in developing countries; and

(e) Respond to scientific, technological and methodological questions that the Conference of the Parties and its subsidiary bodies may put to the body.

3. The functions and terms of reference of this body may be further elaborated by the Conference of the Parties.

ARTICLE 10: SUBSIDIARY BODY FOR IMPLEMENTATION

1. A subsidiary body for implementation is hereby established to assist the Conference of the Parties in the assessment and review of the effective implementation of the Convention. This body shall be open to participation by all Parties and comprise government representatives who are experts on matters related to climate change. It shall report regularly to the Conference of the Parties on all aspects of its work.

2. Under the guidance of the Conference of the Parties, this body shall:

(a) Consider the information communicated in accordance with Article 12, paragraph 1, to assess the overall aggregated effect of the steps taken by the Parties in the light of the latest scientific assessments concerning climate change;

(b) Consider the information communicated in accordance with Article 12, paragraph 2, in order to assist the Conference of the Parties in carrying out the reviews required by Article 4, paragraph 2(d); and

(c) Assist the Conference of the Parties, as appropriate, in the preparation and implementation of its decisions.

ARTICLE 11: FINANCIAL MECHANISM

1 A mechanism for the provision of financial resources on a grant or concessional basis, including for the transfer of technology, is hereby defined. It shall function under the guidance of and be accountable to the Conference of the Parties, which shall decide on its policies, programme priorities and eligibility criteria related to this Convention. Its operation shall be entrusted to one or more existing international entities.

2. The financial mechanism shall have an equitable and balanced representation of all Parties within a transparent system of governance.

3. The Conference of the Parties and the entity or entities entrusted with the operation of the financial mechanism shall agree upon arrangements to give effect to the above paragraphs, which shall include the following:

(a) Modalities to ensure that the funded projects to address climate change are in conformity with the policies, programme priorities and eligibility criteria established by the Conference of the Parties;

(b) Modalities by which a particular funding decision may be reconsidered in light of these policies, programme priorities and eligibility criteria;

(c) Provision by the entity or entities of regular reports to the Conference of the Parties on its funding operations, which is consistent with the requirement for accountability set out in paragraph 1 above; and

(d) Determination in a predictable and identifiable manner of the amount of funding necessary and available for the implementation of this Convention and the conditions under which that amount shall be periodically reviewed.

4. The Conference of the Parties shall make arrangements to implement the above-mentioned provisions at its first session, reviewing and taking into account the interim arrangements referred to in Article 21, paragraph 3, and shall decide whether these interim arrangements shall be maintained. Within four years thereafter, the Conference of the Parties shall review the financial mechanism and take appropriate measures.

5. The developed country Parties may also provide and developing country Parties avail themselves of, financial resources related to the implementation of the Convention through bilateral, regional and other multilateral channels.

ARTICLE 12: COMMUNICATION OF INFORMATION RELATED TO IMPLEMENTATION

1. In accordance with Article 4, paragraph 1, each Party shall communicate to the Conference of the Parties, through the secretariat, the following elements of information:

(a) A national inventory of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol, to the extent its capacities permit, using comparable methodologies to be promoted and agreed upon by the Conference of the Parties;

(b) A general description of steps taken or envisaged by the Party to implement the Convention; and

(c) Any other information that the Party considers relevant to the achievement of the objective of the Convention and suitable for inclusion in its communication, including, if feasible, material relevant for calculations of global emission trends.

2. Each developed country Party and each other Party included in Annex I shall incorporate in its communication the following elements of information:

(a) A detailed description of the policies and measures that it has adopted to implement its commitment under Article 4, paragraphs 2(a) and 2(b), and

(b) A specific estimate of the effects that the policies and measures referred to in subparagraph (a) immediately above will have on anthropogenic emissions by its sources and removals by its sinks of greenhouse gases during the period referred to in Article 4, paragraph 2(a).

3. In addition, each developed country Party and each other developed Party included in Annex II shall incorporate details of measures taken in accordance with Article 4, paragraphs 3, 4 and 5.

4. Developing country Parties may, on a voluntary basis, propose projects for financing, including specific technologies, materials, equipment, techniques or practices that would be needed to implement such projects, along with, if possible, an estimate of all incremental costs, of the reductions of emissions and increments of removals of greenhouse gases, as well as an estimate of the consequent benefits.

5. Each developed country Party and each other Party included in Annex I shall make its initial communication within six months of the entry into force of the Convention for that Party. Each Party not so listed shall make its initial communication within three years of the entry into force of the Convention for that Party, or of the availability of financial resources in accordance with Article 4, paragraph 3. Parties that are least developed countries may make their initial communication at their discretion. The frequency of subsequent communications by all Parties shall be determined by the Conference of the Parties, taking into account the differentiated timetable set by this paragraph.

6. Information communicated by Parties under this Article shall be transmitted by the secretariat as soon as possible to the Conference of the Parties and to any subsidiary bodies concerned. If necessary, the procedures for the communication of information may be further considered by the Conference of the Parties.

7. From its first session, the Conference of the Parties shall arrange for the provision to developing country Parties of technical and financial support, on request, in compiling and communicating information under this Article, as well as in identifying the technical and financial needs associated with proposed projects and response measures under Article 4. Such support may be provided by other Parties, by competent international organizations and by the secretariat, as appropriate.

8. Any group of Parties may, subject to guidelines adopted by the Conference of the Parties, and to prior notification to the Conference of the Parties, make a joint communication in fulfilment of their obligations under this Article, provided that such a communication includes information on the fulfilment by each of these Parties of its individual obligations under the Convention.

9. Information received by the secretariat that is designated by a Party as confidential, in accordance with criteria to be established by the Conference of the Parties, shall be aggregated by the secretariat to protect its confidentiality before being made available to any of the bodies involved in the communication and review of information.

10. Subject to paragraph 9 above, and without prejudice to the ability of any Party to make public its communication at any time, the secretariat shall make communications by Parties under this Article publicly available at the time they are submitted to the Conference of the Parties.

ARTICLE 13: RESOLUTION OF QUESTIONS REGARDING IMPLEMENTATION

The Conference of the Parties shall, at its first session, consider the establishment of a multilateral consultative process, available to Parties on their request, for the resolution of questions regarding the implementation of the Convention.

ARTICLE 14: SETTLEMENT OF DISPUTES

1. In the event of a dispute between any two or more Parties concerning the interpretation or application of the Convention, the Parties concerned shall seek a settlement of the dispute through negotiation or any other peaceful means of their own choice.

2. When ratifying, accepting, approving or acceding to the Convention, or at any time thereafter, a Party which is not a regional economic integration organization may declare in a written instrument submitted to the Depositary that, in respect of any dispute concerning the interpretation or application of the Convention, it recognizes as compulsory ipso facto and without special agreement, in relation to any Party accepting the same obligation:

(a) Submission of the dispute to the International Court of Justice, and/or

(b) Arbitration in accordance with procedures to be adopted by the Conference of the Parties as soon as practicable, in an annex on arbitration.

A Party which is a regional economic integration organization may make a declaration with like effect in relation to arbitration in accordance with the procedures referred to in subparagraph (b) above.

3. A declaration made under paragraph 2 above shall remain in force until it expires in accordance with its terms or until three months after written notice of its revocation has been deposited with the Depositary.

4. A new declaration, a notice of revocation or the expiry of a declaration shall not in any way affect proceedings pending before the International Court of Justice or the arbitral tribunal, unless the parties to the dispute otherwise agree.

5. Subject to the operation of paragraph 2 above, if after twelve months following notification by one Party to another that a dispute exists between them, the Parties concerned have not been able to settle their dispute through the means mentioned in paragraph 1 above, the dispute shall be submitted, at the request of any of the parties to the dispute, to conciliation.

6. A conciliation commission shall be created upon the request of one of the parties to the dispute. The commission shall be composed of an equal number of members appointed by each party concerned and a chairman chosen jointly by the members appointed by each party. The commission shall render a recommendatory award, which the parties shall consider in good faith.

7. Additional procedures relating to conciliation shall be adopted by the Conference of the Parties, as soon as practicable, in an annex on conciliation.

8. The provisions of this Article shall apply to any related legal instrument which the Conference of the Parties may adopt, unless the instrument provides otherwise.

ARTICLE 15: AMENDMENTS TO THE CONVENTION

1. Any Party may propose amendments to the Convention.

2. Amendments to the Convention shall be adopted at an ordinary session of the Conference of the Parties. The text of any proposed amendment to the Convention shall be communicated to the Parties by the secretariat at least six months before the meeting at which it is proposed for adoption. The secretariat shall also communicate proposed amendments to the signatories to the Convention and, for information, to the Depositary.

3. The Parties shall make every effort to reach agreement on any proposed amendment to the Convention by consensus. If all efforts at consensus have been exhausted, and no agreement reached, the amendment shall as a last resort be adopted by a three-fourths majority vote of the Parties present and voting at the meeting The adopted amendment shall be communicated by the secretariat to the Depositary, who shall circulate it to all Parties for their acceptance.

4. Instruments of acceptance in respect of an amendment shall be deposited with the Depositary. An amendment adopted in accordance with paragraph 3 above shall enter into force for those Parties having accepted it on the ninetieth day after the date of receipt by the Depositary of an instrument of acceptance by at least three fourths of the Parties to the Convention.

5. The amendment shall enter into force for any other Party on the ninetieth day after the date on which that Party deposits with the Depositary its instrument of acceptance of the said amendment.

6 For the purposes of this Article, "Parties present and voting" means Parties present and casting an affirmative or negative vote.

ARTICLE 16: ADOPTION AND AMENDMENT OF ANNEXES TO THE CONVENTION

1. Annexes to the Convention shall form an integral part thereof and, unless otherwise expressly provided, a reference to the Convention constitutes at the same time a reference to any annexes thereto. Without prejudice to the provisions of Article 14, paragraphs 2(b) and 7, such annexes

shall be restricted to lists, forms and any other material of a descriptive nature that is of a scientific, technical, procedural or administrative character.

2. Annexes to the Convention shall be proposed and adopted in accordance with the procedure set forth in Article 15, paragraphs 2, 3 and 4.

3. An annex that has been adopted in accordance with paragraph 2 above shall enter into force for all Parties to the Convention six months after the date of the communication by the Depositary to such Parties of the adoption of the annex, except for those Parties that have notified the Depositary, in writing, within that period of their non-acceptance of the annex. The annex shall enter into force for Parties which withdraw their notification of non-acceptance on the ninetieth day after the date on which withdrawal of such notification has been received by the Depositary.

4. The proposal, adoption and entry into force of amendments to annexes to the Convention shall be subject to the same procedure as that for the proposal, adoption and entry into force of annexes to the Convention in accordance with paragraphs 2 and 3 above.

5. If the adoption of an annex or an amendment to an annex involves an amendment to the Convention, that annex or amendment to an annex shall not enter into force until such time as the amendment to the Convention enters into force.

ARTICLE 17: PROTOCOLS

1. The Conference of the Parties may, at any ordinary session, adopt protocols to the Convention.

2. The text of any proposed protocol shall be communicated to the Parties by the secretariat at least six months before such a session

3. The requirements for the entry into force of any protocol shall be established by that instrument.

4. Only Parties to the Convention may be Parties to a protocol.

5. Decisions under any protocol shall be taken only by the Parties to the protocol concerned.

ARTICLE 18: RIGHT TO VOTE

1 Each Party to the Convention shall have one vote, except as provided for in paragraph 2 below.

2. Regional economic integration organizations, in matters within their competence, shall exercise their right to vote with a number of votes equal to the number of their member States that are Parties to the Convention. Such an organization shall not exercise its right to vote if any of its member States exercises its right, and vice versa.

ARTICLE 19: DEPOSITARY

The Secretary-General of the United Nations shall be the Depositary of the Convention and of protocols adopted in accordance with Article 17.

ARTICLE 20: SIGNATURE

This Convention shall be open for signature by States Members of the United Nations or of any of its specialized agencies or that are Parties to the Statute of the International Court of Justice and by regional economic integration organizations at Rio de Janeiro, during the United Nations Conference on Environment and Development, and thereafter at United Nations Headquarters in New York from 20 June 1992 to 19 June 1993.

ARTICLE 21: INTERIM ARRANGEMENTS

1. The secretariat functions referred to in Article 8 will be carried out on an interim basis by the secretariat established by the General Assembly of the United Nations in its resolution 45/212 of 21 December 1990, until the completion of the first session of the Conference of the Parties.

2. The head of the interim secretariat referred to in paragraph 1 above will cooperate closely with the Intergovernmental Panel on Climate Change to ensure that the Panel can respond to the need for objective scientific and technical advice. Other relevant scientific bodies could also be consulted.

3. The Global Environment Facility of the United Nations Development Programme, the United Nations Environment Programme and the International Bank for Reconstruction and Development shall be the international entity entrusted with the operation of the financial mechanism referred to in Article 11 on an interim basis In this connection, the Global Environment Facility should be appropriately restructured and its membership made universal to enable it to fulfil the requirements of Article 11.

ARTICLE 22: RATIFICATION, ACCEPTANCE, APPROVAL OR ACCESSION

1. The Convention shall be subject to ratification, acceptance, approval or accession by States and by regional economic integration organizations. It shall be open for accession from the day after the date on which the Convention is closed for signature. Instruments of ratification, acceptance, approval or accession shall be deposited with the Depositary.

2 Any regional economic integration organization which becomes a Party to the Convention without any of its member States being a Party shall be bound by all the obligations under the Convention. In the case of such organizations, one or more of whose member States is a Party to the Convention, the organization and its member States shall decide on their respective responsibilities for the performance of their obligations under the Convention. In such cases, the

organization and the member States shall not be entitled to exercise rights under the Convention concurrently.

3. In their instruments of ratification, acceptance, approval or accession, regional economic integration organizations shall declare the extent of their competence with respect to the matters governed by the Convention. These organizations shall also inform the Depositary, who shall in turn inform the Parties, of any substantial modification in the extent of their competence.

ARTICLE 23: ENTRY INTO FORCE

1. The Convention shall enter into force on the ninetieth day after the date of deposit of the fiftieth instrument of ratification, acceptance, approval or accession.

2. For each State or regional economic integration organization that ratifies, accepts or approves the Convention or accedes thereto after the deposit of the fiftieth instrument of ratification, acceptance, approval or accession, the Convention shall enter into force on the ninetieth day after the date of deposit by such State or regional economic integration organization of its instrument of ratification, acceptance, approval or accession.

3. For the purposes of paragraphs 1 and 2 above, any instrument deposited by a regional economic integration organization shall not be counted as additional to those deposited by States members of the organization.

ARTICLE 24: RESERVATIONS

No reservations may be made to the Convention.

ARTICLE 25: WITHDRAWAL

1 At any time after three years from the date on which the Convention has entered into force for a Party, that Party may withdraw from the Convention by giving written notification to the Depositary.

2. Any such withdrawal shall take effect upon expiry of one year from the date of receipt by the Depositary of the notification of withdrawal, or on such later date as may bespecified in the notification of withdrawal.

3. Any Party that withdraws from the Convention shall be considered as also having withdrawn from any protocol to which it is a Party

ARTICLE 26: AUTHENTIC TEXTS

The original of this Convention, of which the Arabic, Chinese, English, French, Russian and Spanish texts are equally authentic, shall be deposited with the Secretary- General of the United Nations

IN WITNESS WHEREOF the undersigned, being duly authorized to that effect, have signed this Convention.

DONE at New York this ninth day of May one thousand nine hundred and ninety-two.

ANNEX I

Australia
Austria
Belarus[a]
Belgium
Bulgaria[a]
Canada
Crotia[a]
Czech Republic[a]
Denmark
European Economic Community
Estonia[a]
Finland
France
Germany
Greece
Hungary[a]
Iceland
Ireland
Italy
Japan
Latvia[a]
Liechtenstein
Lithuania[a]
Luxembourg
Monaco
Netherlands
New Zealand
Norway
Poland[a]
Portugal
Romania[a]
Russian Federation[a]
Slovakia[a]
Slovenia[a]
Spain
Sweden
Switzerland
Turkey
Ukraine[a]
United Kingdom of Great Britain and Northern Ireland
United States of America

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[a] Countries that are undergoing the process of transition to a market economy

Annex II

Australia
Austria
Belgium
Canada
Denmark
European Economic Community
Finland
France
Germany
Greece
Iceland
Ireland
Italy
Japan
Luxembourg
Netherlands
New Zealand
Norway
Portugal
Spain
Sweden
Switzerland
Turkey
United Kingdom of Great Britain and Northern Ireland
United States of America

Congressional Research Service Documents

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CRS Report for Congress

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Global Climate Change: The Energy Tax Incentives In the President's FY1999 Budget

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Economics Division

Summary

The President's FY1999 budget includes several energy tax incentives designed to help the United States reduce greenhouse gases that are linked to possible global warming. These incentives subsidize energy conservation, energy efficiency, and substitution toward alternative fuels such as solar power and electricity produced from biomass and wind. The conservation and efficiency tax incentives are in the form of nonrefundable tax credits for energy-saving capital goods, and they target each of the energy end-use sectors: transportation, industry, residential and commercial. In addition, some of the tax credits are intended to directly reduce the amount of harmful greenhouse gases that would otherwise be released into the atmosphere. Most of the incentives are new, some resembling versions of energy tax incentives that were enacted under President Carter's Energy Tax Act of 1978 (as amended), but have since expired. Two of the provisions constitute a liberalization of existing energy tax subsidies.

Residential and Commercial Buildings

Three tax credits are proposed in the FY1999 budget to reduce the use of conventional energy — electricity from fossil fuels, natural gas, heating oil, etc. — in residential and commercial buildings: (1) tax credits for equipment that uses solar energy; (2) a tax credit for the purchase of energy-efficient, new homes; and (3) a tax credit for purchases of energy efficiency equipment, and materials.

Tax Credits for Solar Energy Equipment. The Administration proposes a tax credit for two types of solar energy using equipment: (1) a 15% tax credit for up to $13,334 in investments in rooftop solar equipment that uses photovoltaic cells to generate electricity, for a maximum tax credit of $2,000; and (2) a 15% tax credit for up to $6,667 in investments in solar water heating equipment (other than swimming pools), for a maximum tax credit of $1,000. Solar equipment installed in either a personal residence or a business would qualify for this tax credit, which would be "nonrefundable," i.e., limited by the amount of tax otherwise owed.

The credit for photovoltaic systems would last for 7 years, beginning in 1999; the credit for water heating systems would last for 5 years, also beginning in 1999. Photovoltaics are solar cells made of semiconductor material capable of converting sunlight directly into electricity. A photovoltaic solar system combines individual cells into a panel, which can be interconnected and used as part of a sunlight-absorbing roof or as separate self-contained electricity generating system on the ground.

Current law provides for a 10% tax credit for investment in solar photovoltaic systems or for solar equipment used to heat or cool a structure or for solar process heat. Only businesses qualify for this credit, which also applies to geothermal systems. The equivalent credit for residential solar systems expired at the end of 1985. The business solar credit is the remnant of the more extensive system of residential and business tax credits for conservation and renewable energy that were part of President Carter's National Energy Plan of 1978, but which largely expired at the end of 1985. Only the business energy tax credits were extended several times beyond 1985, and for gradually fewer and fewer types of energy equipment. Under President Clinton's FY1999 proposal, businesses that invest in qualifying solar equipment would have to choose between the current 10% tax credit and the proposed 15% tax credit.

Tax Credit for New Energy Efficient Homes. Some federal laws and certain states require energy-using home appliances, heating and cooling equipment, and insulation to meet certain energy efficiency standards. But there are otherwise no special tax incentives to encourage the supply of energy efficient homes. The President's FY1999 budget proposes a tax credit for the cost of a new home that would meet certain specified and stringent energy efficiency standards. The tax credit would equal to 1% of the home's purchase price up to a maximum credit of $2,000 for homes purchased between 1999 and 2003,and $1,000 for homes purchased during either 2004 or 2005. Qualifying new homes would have to be at least 50% more energy efficient than the standard for single family homes specified in the Model Energy Code.

Tax Credit for Energy-Efficient Building Equipment. The last of the three tax credits to reduce the use of conventional energy in residential and commercial buildings is a 20% tax credit for the cost of six types of advanced energy-efficient equipment and technologies for space heating and cooling and hot water heaters, as follows:

- More efficient air conditioners
- High energy-efficiency advanced natural gas water heaters
- More energy efficient natural gas heat pumps
- Energy efficient electric heat pumps
- Energy efficient electric heat pump water heaters
- Fuel cells.

Each of these six types of qualifying equipment would have to satisfy stringent energy efficiency standards, as compared with current types of equivalent non-energy efficient equipment. Only costs up to a maximum ceiling — as yet unspecified — would qualify for the tax credit. The credit would be available for the costs of qualifying equipment purchased during the 5-year period from January 1, 1999, to December 3, 2004.

Under current law, no tax credits or other tax incentives are provided for equipment to make business stuctures more energy efficient. The 1978 Energy Tax Act provided for a system of business energy investment tax credits for several categories of energy conservation property — called "specially defined energy property," — but these were essentially equipment used in manufacturing or industrial processes rather than in buildings. As with the 1978 solar energy tax credits, these energy equipment tax credits also expired at the end of 1985.[1]

Industrial Energy Use

Under the President's proposal, three types of industrial energy equipment would qualify for a 10% investment tax credit: (1) combined heat and power systems ; (2) certain circuitbreaker equipment; and (3) certain recycling equipment.

Tax Credit for Combined Heat and Power Systems. A 10% investment tax credit would be provided for businesses that invest in combined heat and power systems that meet certain energy efficiency standards. Combined heat and power systems capture the thermal energy (for either heating or cooling) or the mechanical power — whatever the case may be — that would otherwise be wasted when industrial manufacturing processes generate electricity. Thus, they are essentially a type of cogeneration equipment: with one source of energy, a company can simultaneously power its turbines to generate electricity and either heat and cool its building or provide mechanical power needed in some manufacturing process. Fuel inputs are conserved by making an energy-using process — the generation of electrical power — more efficient: the otherwise wasted energy would be harnessed and would be used in the same process.

Current tax law provides no tax credit for this type of industrial energy equipment. Cogeneration equipment was added in 1980 to the list of property qualifying for the 10% business energy investment tax credits under the original Energy Tax Act of 1978. These expired at the end of 1982, 3 years before the expiration of the residential energy tax credits and the other business energy tax credits.

Tax Credit for New Types of Circuitbreakers. Some large circuit breakers used by public power companies (electric utilities) in the transmission and distribution of electricity use a gas (sulfur hexafloride) that leaks into the atmosphere when the breakers age. Under the President's proposal, a 10% tax credit would be available for the replacement of these leaky, older (pre-1985) circuit breakers with new power circuitbreaker equipment. The Administration believes that sulfur hexafloride is an extremely harmful greenhouse gas. No similar tax credit or other tax incentive has ever been provided.

Tax Credit for Certain Recycling Equipment. A 10% investment tax credit would be provided to producers of semiconductors for investments in equipment used to recycle two harmful greenhouse gases used in the production of semiconductors: perfluorocarbon (PFC) and hydrofluorocarbon (HFC). The tax credit would apply to new equipment placed in service in the 5-year period beginning January 1, 1999, and ending December 31, 2003. Under current law no special tax credit is provided for this type of recycling

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[1]U.S. Library of Congress. Congressional Research Service. *An Explanation of the Business Energy Investment Tax Credits.* CRS Report 85-25 E by Salvatore Lazzari. January 24, 1985. Washington.

equipment, although such equipment may be depreciated over 5 years. The 1978 business energy tax credit provided for a 10% tax credit for businesses that recycled solid wastes. This tax credit expired at the end of 1982.

Transportation Energy Use

Two tax incentives are proposed to conserve petroleum in the transportation sector: (1) a tax credit for fuel efficient vehicles; and (2) a higher income tax exemption for mass transit fringe benefits.

Tax Credit for Fuel Efficient Vehicles. A new tax credit would be available for the purchase of cars and light trucks (including minivans, sport utility vehicles, and pickups) that are at least twice as economical as current vehicles in their class. For vehicles rated at least twice the base fuel economy, the credit would be as follows: $3,000 if purchased between January 1, 2000, and January 1, 2004; $2,000 if purchased during 2004; and $1,000 if purchased in either 2005 or 2006. If the vehicle is rated at least 3-times the base fuel economy, the tax credit would be as follows: $4,000 if purchased between January 1, 2002, and January 1, 2007; $3,000 if purchased during 2007; $2,000 if purchased during 2008; and $1,000 if purchased during either 2009 or 2010.

Current tax law contains several tax incentives — and some nontax disincentives — to conserve conventional, petroleum based motor fuels, particularly gasoline and diesel fuel. First, gasoline and diesel fuel are taxed at the rates of 18.4¢ and 24.4¢ per gallon. Second, an excise tax is imposed on the sale of domestically produced or imported "gas guzzlers" that do not meet the fuel economy standards (the CAFE standards) established by the Environmental Protection Agency. The tax rate is graduated, ranging from $1,000 for vehicles rated between 21.5 and 22.5 miles per gallon (MPG) and $7,700 for vehicles rated at less than 12.5 MPG.

In addition to taxes on conventional fuels and "guzzlers" of conventional fuels, federal tax law provides a deduction for clean-fuel vehicles and a tax credit for electric vehicles. Since 1992, a federal tax deduction has been available for individuals or businesses that purchase vehicles that run on alternative fuels.[2] Taxpayers can deduct from adjusted gross income a portion of the costs associated with the purchase of dedicated alternative fuel vehicles (AFVs), or the costs of converting vehicles so that they can operate on clean-burning alternative fuels (dual fuel AFVs) in addition to gasoline. Dedicated AFV's are new vehicles designed to run on an alternative fuel only.

For dedicated AFVs, costs up to $2,000 for qualified property can be deducted for a vehicle up to 10,000 lbs., up to $5,000 for a truck or van of 10,000 to 26,000 lbs., and up to $50,000 for a truck or van over 26,000 lbs. Qualified property for a dedicated AFV includes the full cost of the engine, the fuel delivery system, and the exhaust system. For a dual-fuel vehicle, the qualified cost is limited to the incremental cost of the same components compared with the systems for conventional fuels. Alternative fuels are defined as compressed natural gas, liquefied petroleum gas, liquefied natural gas,

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[2]For a more detailed discussion of these provisions see: U.S. Library of Congress. Congressional Research Service. *Energy Tax Provisions of the Energy Policy Act of 1992.* CRS Report 94-525E, by Salvatore Lazzari. Washington, 1994.

hydrogen, electricity, and any other fuel that includes 85% alcohol fuels, ether, or any combination of these. In addition, all of the property that qualifies for the deduction — the new vehicle, or the conversions equipment — must be new. Qualifying vehicles must meet any applicable federal and state environmental standards. For business taxpayers, the basis of the property for purposes of the depreciation deduction is reduced by the amount of clean-fuel-vehicle deduction. In general, each of these deductions terminates at the end of 2004. But there is a phase-out provision in the case of new clean-fuel burning vehicles or retrofit equipment. The deduction is phased-out evenly over a 3-year period beginning in January 2002.

In lieu of a tax deduction, consumers that purchase an electric vehicle can claim a 10% nonrefundable tax credit for the cost of the vehicle placed in service prior to 2005. The maximum credit is $4,000.[3] Also, for businesses that purchase electric vehicles, the maximum amount that may be deducted annually for depreciation is three times larger than the depreciation limit for other types of automobiles. In general, the amount that businesses may deduct annually for depreciation of an automobile is limited to $2,560 the 1st year, $4,100 the 2nd year, $2,450 the 3rd year, and $1,475 each subsequent year in the recovery period. Each of these amounts are adjusted annually for inflation that has occurred since 1987 so that the amounts for 1997 (for most cars) were $3,160, $5,000, $3,050, and $1,775. For electric vehicles, however, the base amounts are $7,680, $12,300, $7,350, and $4,425, respectively. These annual limits are also adjusted for inflation after 1997. The higher depreciation limits for electric vehicles was a provision of the Taxpayer Relief Act of 1997.

Higher Tax Exemption for Mass Transit Fringe Benefits. The President's budget proposal includes a provision to increase the income tax exemption for employer payment or reimbursement for the costs of mass transit (bus fares, subway or train fares) or van pools costs to the level of tax exemption for employer provided parking benefits. Currently, federal income tax law stipulates that mass transit or van pool payments above $65 per month must be reported as income — i.e., up to $65 per month is exempt from taxation. Current tax law also taxes employer provided parking or reimbursements for parking expenses above $175 per month — i.e., the exemption for such expenses is $175 per month. The President's proposal would raise the exemption for mass transit and van pool passes to $175 per month, thus equalizing the two transportation fringe benefits..

Tax Credit for Electricity Produced from Wind and Biomass

The President's FY1999 budget would extend by 5 years the current tax credit for electricity produced from wind and biomass. Under current law, an income tax credit is provided, as part of a tax code section, in the amount of 1.5¢ /kWh. (in real, 1992 dollars) for electricity generated from wind or from closed-loop biomass systems. The credit for 1997 was 1.6¢ /kWh. Closed loop biomass systems use plants grown exclusively for electricity production. Thus, the credit is not available for the use of waste and most other biomass to generate electricity. Any plant used exclusively for electrical generation, except standing timber, which is specifically disqualified, qualifies for the credit. The

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[3]The Taxpayer Relief Act of 1997 amended the excise tax treatment of luxury vehicles to make it more difficult for clean-fuel and electric vehicles to be designated as luxuries subject to that tax.

credit is available to facilities that begin service after 1992 (for biomass) and 1993 (for wind) but before July 1, 1999. Any qualified facility that opens during that period can then earn the tax credit for its first 10 years of operation. The President's proposal would extend this to July 1, 2004.

This tax credit is phased out, proportionately, as the reference price — the average price of renewable electricity sold by qualified wind and biomass facilities — rises from 8 ¢ /kWh to 11¢ / kWh. Both the credit amount and the phase-out limit is adjusted annually for inflation. The credit is also to be reduced during any taxable year for which the project has received grants, proceeds from tax-exempt bonds, subsidized energy financing, and any other credit allowable for property that is part of the project.

For 1994, the reference prices were 5.4¢ / kWh for facilities producing electricity from wind, and 0.0¢ / kWh for facilities producing electricity from closed-loop biomass systems. For 1997, the reference prices were 6.4¢ and 0.0¢, respectively. Since both reference prices were less than the threshold prices for the credit phase-out, the renewable electricity credit was not phased-out and remained at 1.5¢ / kWh. In calender year 1996, there were no sales of electricity produced from closed-loop biomass energy resources under contracts signed after December 31, 1989.

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Global Climate Change: Research and Development Provisions in the President's Climate Change Technology Initiative

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Summary

Following the international agreement to reduce greenhouse gas emissions reached in Kyoto in December 1997, the Clinton Administration in January 1998 proposed a Climate Change Technology Initiative (CCTI). Through the CCTI, the Administration is seeking congressional authorization for $3.6 billion in tax credits as incentives, and $2.7 billion in R&D to be invested over 5 years in partnership with industry as a means of curbing greenhouse gas emissions in the United States. (Further details about the tax credits can be found in CRS Report 98-193 E *"Global Climate Change: The Energy Tax Incentives In the President's FY1999 Budget"* by Salvatore Lazzari). Given that the Kyoto Protocol likely will not be submitted this year to the Senate for its advice and consent to ratification and given that it has not yet entered into force worldwide, the view has been expressed among those critical of the Protocol in its present form that the CCTI is a "backdoor" through which the Administration can begin to take action anyway to implement the protocol. Further, how effective investing approximately $540 million a year in R&D in a mix of new and redirected funds and activities will be in reducing greenhouse gas emissions remains to be seen. This report will be updated as needed.

Introduction

On October 22, 1997, in a speech at the National Geographic Society in Washington, DC, the President announced a nine-point plan designed to reduce the nation's carbon and other greenhouse gas emissions. Included in the plan was a 5-year package with $5 billion of tax incentives and R&D investments to encourage energy efficiency and to help develop low-carbon energy sources. To make good on that commitment, the Administration, in January 1998, proposed the Climate Change Technology Initiative (CCTI), following the international agreement reached in Kyoto in December 1997, to reduce greenhouse gas emissions[1]. The CCTI, a mix of new and redirected funds and activities, again spans five years but calls for a total of $6.3 billion, with a $2.7 billion increase in R&D investments. The following tables summarize the R&D portion of the CCTI. Further details may be found in a package of FY1999 budget briefing materials on the CCTI, dated February 2, 1998. That package and other related information also are available on-line at http://www.whitehouse.gov/Initiatives/Climate/indexp.html

CCTI $ millions (for R&D and in total)

Federal entity	1997 actual	1998 estimate	1999 proposed	$ change 1998 to 1999	Total increase 1999-2003
DOE	657	729	1060	+331	+1,899
EPA	86	90	205	+115	+677
HUD	—	—	10	+10	+10
Commerce	—	—	7	+7	+38
USDA	—	—	10	+10	+86
R&D total	743	819	1,292	+473	+2,710
CCTI total	743	819	1,713	+894	+6,345

DOE=Department of Energy; EPA=Environmental Protection Agency; HUD=Housing and Urban Development Department; USDA=Department of Agriculture.

The main foci of the R&D efforts contained in the CCTI are the four major carbon-emitting sectors of the economy (buildings, industry, transportation, and electricity), efforts and technologies for removing and sequestering carbon, federal facilities, and cross-cutting analyses and research. They are summarized in the following table and text.

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[1] For additional information see CRS Issue Brief 89005, *Global Climate Change*; and CRS Report 98-2, *Global Climate Change Treaty: Summary of the Kyoto Protocol.*

CCTI $ millions (by area of focus)

Focus area	1998 estimate	1999 proposed	$ change; 1998 to 1999
Buildings	146	264	+118
Industry	156	216	+60
Transportation	246	356	+110
Electricity	220	312	+92
Carbon sequestration and cross-cutting research	0	42	+42
Policy analysis, market incentives	6	26	+20
Program direction	45	57	+12
Direct R&D total	819	1,273	+454

Carbon Emitting Sectors of the Economy

Buildings. The Department of Energy (DOE) and Environmental Protection Agency (EPA) will be led by the Housing and Urban Development Department (HUD) on a team to work with the housing industry to research, develop, demonstrate, and deploy housing technologies and practices that are highly efficient, inexpensive, and attractive to consumers. This joint effort is called the Partnership for Advanced Technologies in Housing (PATH).

The DOE will fund R&D into ways to reduce the costs of solar thermal and rooftop photovoltaic systems. The DOE also is increasing R&D on buildings, systems modeling, and on major components including next-generation heat-pumps, cooling systems, furnaces, and lighting.

Industry. Efforts to research and develop fuel cells, advanced turbines, other technologies, and new approaches to capture useful work or heat in factories or commercial settings will be accelerated, especially in cost-shared arrangements involving DOE, EPA, U.S. Department of Agriculture (USDA), U.S. Department of Commerce, industry teams, and consortia.

Transportation. The Partnership for a New Generation of Vehicles (PNGV) involves industry and the DOE, EPA, Commerce, National Science Foundation, and Department of Transportation (DOT) working together to develop cars that consumers can afford and will want to buy, that will meet all safety and environmental standards and get up to 80 miles per gallon of gasoline. The combined request for PNGV-related activities for FY1999 is $277 million. The FY1998 amount is $227 million.

The Partnership for Light and Heavy Trucks is similar to the PNGV, but focuses on cleaner, more efficient diesel engines for light and heavy trucks, and involves the DOE, EPA, and Department of Defense.

Sustainable transportation programs will promote alternatives to single-occupancy vehicles. Such programs in the EPA and DOE will be coordinated with extant and planned DOT activities (DOT work in this area is not funded within the CCTI).

Electricity. Research partnerships in renewable energy and related technologies, including wind, photovoltaics, geothermal, biomass, hydropower, hydrogen production and storage, and superconductivity, will be expanded by $100 million, which is 37 percent over FY1998.

Current Nuclear Regulatory Commission licenses call for the retirement of 60 gigawatts of nuclear electric generating capacity by 2015 (current total electricity generating capacity is about 710 gigawatts). The DOE will begin R&D efforts into technologies that will allow the safe operation of extant nuclear power plants by 10 to 20 years, helping ease the transition to other low- and no-carbon energy sources.

The DOE also will begin in FY1999 an R&D program into new ways to combust coal with far fewer carbon emissions.

Carbon Removal and Sequestration

The DOE will fund R&D to find ways (including physical, biochemical, and microbial) to remove carbon dioxide from combustion gases and sequester it, i.e., store it so that it does not enter the atmosphere.

The USDA will begin research into ways to enhance the carbon-sequestering capabilities of agricultural species.

Within Commerce, the National Institute for Standards and Technology will fund complementary biotechnology research on plant metabolism and carbon use.

Cross-Cutting Analysis and Research

Whether and how to implement an industrial carbon emission reduction program and a domestic trading system will be researched by the federal government, including the DOE, with input by stakeholders.

New research findings from the Global Change Research Program will be studied by the DOE and other federal entities to try to determine optimal geographic and technological responses.

Issues for Congress

Several committees of relevant jurisdiction in the House and the Senate have held hearings in the current session, reviewing the details of the Kyoto Protocol and related issues. Of particular interest is whether enacting measures that would focus on carbon dioxide and other greenhouse gas reductions to meet the terms of the protocol could be achieved at little or no net cost to the national economy, as some have suggested, or whether the protocol might result in increased taxes, loss of jobs, or a dramatic jump in energy costs for Americans, as others have suggested. Other questions have arisen as to whether any environmental benefits would, indeed, be achieved at all under the levels of reduction mandated by the protocol.

With the submission of the CCTI as part of the President's FY1999 budget, those committees have also commenced looking at details of the CCTI with an eye toward determining what portion of the request might constitute sound contingency actions versus what portion might prematurely commit the United States to the Kyoto Protocol, to which the Senate has not yet given its advice and consent to ratification and which has not yet entered into force internationally. Concerns have been voiced among those critical of the protocol in its present form that the CCTI might be a "backdoor" through which the Administration could begin to take action anyway to implement the terms of the protocol.

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Global Climate Change Treaty: The Kyoto Protocol

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Summary

Negotiations on the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) were completed December 11, 1997, committing the industrialized nations to specified, legally binding targets for emissions of six "greenhouse gases." The treaty will open for signature on March 16, 1998. The United States played a prominent role in these negotiations, and agreed to a target of reducing greenhouse gases by 7% below 1990 levels during a "commitment period" between 2008-2012. Because of the way sinks, which remove these gases from the atmosphere, are counted and because of other provisions discussed in this report, the actual reduction of emissions required to meet the target within the United States is estimated to be lower than 7%. The Administration has indicated that until developing countries also make commitments to participate in greenhouse gas limitations, it will not submit the protocol to the Senate for advice and consent, thereby delaying any possibility of ratification until at least after a November 1998 meeting of the parties in Buenos Aires, Argentina. At mid-year June 1998 meetings of the UNFCCC subsidiary bodies, a number of the more difficult issues were discussed, but results of these meetings were generally inconclusive. In Congress, several committees have held hearings on the Kyoto Protocol and its implications, and a number of bills, resolutions and provisions in appropriations bills have been introduced or considered, mostly to limit activities of the U.S. government that are or could be seen as related to carrying out the goals of the Kyoto Protocol.

Background

Responding to concerns that human activities are increasing concentrations of "greenhouse gases" (such as carbon dioxide and methane) in the atmosphere, most nations of the world joined together in 1992 to sign the United Nations Framework Convention on Climate Change (UNFCCC). The United States was one of the first nations to ratify this treaty. It included a legally non-binding, voluntary pledge that the major industrialized/developed nations would reduce their greenhouse gas emissions to 1990 levels by the year 2000. However, as scientific consensus grew that human activities are having a discernible impact on global climate systems, possibly causing a warming of the Earth that could result in significant impacts such as sea level rise, changes in weather patterns and health effects—and as it became apparent that major nations such as the United States and Japan would not meet the voluntary stabilization target by 2000—Parties to the treaty decided in 1995 to enter into negotiations on a protocol to establish legally binding limitations or reductions in greenhouse gas emissions. It was decided by the Parties that this round of negotiations would establish limitations only for the developed countries (those listed in Annex 1 to the UNFCCC, including the former Communist countries, and referred to as "Annex 1 countries"; developing countries are referred to as "non-Annex 1 countries").[1]

During negotiations that preceded the December 1-11, 1997, meeting in Kyoto, Japan, little progress was made, and the most difficult issues were not resolved until the final days—and hours—of the Conference. There was wide disparity among key players especially on three items: (1) the amount of binding reductions in greenhouse gases to be required, and the gases to be included in these requirements; (2) whether developing countries should be part of the requirements for greenhouse gas limitations; and (3) whether to allow emissions trading and joint implementation, which allow credit to be given for emissions reductions to a country that brings about the actual reductions in other countries or locations where they may be cheaper to attain.

The United States proposal was for a reduction in all six major greenhouse gases to 1990 levels by the period 2008-2012, with joint implementation allowed. The European Union (EU) argued strongly for a 15% reduction from 1990 levels by 2010 for three greenhouse gases, using a "bubble," or cumulative, approach for the nations within the EU, but no joint implementation beyond that. Japan proposed a 5% reduction from 1990 levels for three greenhouse gases. The group of developing countries (known as the G77) proposed that developed countries should stabilize their emissions of greenhouse gases at 1990 levels by 2000, then reduce them by 15% by 2010, with further reductions of 20%—for a total of 35% reduction by 2020 below 1990 levels.

Following completion of the Protocol in December of 1997, details of a number of the more difficult issues remained to be negotiated and resolved (see below). Some of these were taken up at June 2-12, 1998 meetings of the subsidiary bodies of the FCCC on implementation and scientific and technical affairs. These discussions were generally inconclusive, and consideration and work on the details of these unresolved concerns continues. Formal discussion and negotiation will resume at the COP-4 meeting in November in Buenos Aires, Argentina.

Summary of the Kyoto Protocol to the UNFCCC

The Kyoto Protocol was completed in haste during an extension of the Kyoto meeting beyond its December 10 deadline, into the morning of December 11. It contains a number of areas for which details will have to be worked out over the next year. The

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[1]For additional information on the negotiations in Kyoto and related background, see CRS Report 97-1000, *Global Climate Change Treaty: Negotiations and Related Issues*; and CRS Issue Brief 89005, *Global Climate Change*.

Protocol opened for signature March 16, 1998, and will enter into force when 55 nations have ratified it, provided that these ratifications include Annex I Parties that account for at least 55% of total carbon dioxide emissions in 1990. At the end of July, 38 countries had signed the treaty, including the European Union and most of its members, Canada, Japan, China, and a range of developing countries.

The major commitments in the treaty on the most controversial issues are as follows:

Emissions Reductions. The United States would be obligated under the Protocol to a reduction of 7% below 1990 levels for three greenhouse gases (including carbon dioxide), and below 1995 levels for the three man-made gases, averaged over the commitment period 2008 to 2012. The Protocol states that Annex I Parties are committed—individually or jointly—to ensuring that their aggregate anthropogenic carbon dioxide equivalent emissions of greenhouse gases do not exceed amounts assigned to each country in Annex B to the Protocol, "with a view to reducing their overall emissions of such gases by at least 5% below 1990 levels in the commitment period 2008 to 2012." Annex A lists the 6 major greenhouse gases covered by the treaty[2].

Annex B lists 39 nations, including the United States, the European Union plus the individual EU nations, Japan, and many of the former Communist nations. The amounts for each country are listed as percentages of the base year, 1990 (except for some former Communist countries), and range from 92% (a reduction of 8%) for most European countries—to 110% (an increase of 10%) for Iceland. The United States is committed on this list to 93%, or a reduction of 7%, to be achieved as an average over the five years 2008-2012.

Based on projections of the growth of emissions using current technologies and processes, the reduction in greenhouse gas emissions required of the United States would likely be between 20% and 30% below where it would be otherwise by the 2008-2012 budget period.[3] However, according to Administration officials, based on the accounting method adopted in the Protocol, which includes (as the United States had urged) greenhouse gas sinks, it appears that the actions that must be taken in to reduce emissions within the United States, after sinks are counted, would be substantially less than 7%—probably in the range of 2 to 3%. The Administration also is assuming that a significant portion of its 7% target could be met through some combination of emissions trading and joint implementation.

Developing Country Responsibilities. The United States had taken a firm position that "meaningful participation" of developing countries in commitments made in the Protocol is critical to approval of the treaty by the U.S. Senate, and it argued that success in dealing with the issue of climate change and global warming would require such participation. The developing country bloc argued that the Berlin Mandate—the terms of reference of the Kyoto negotiations—clearly excluded them from new commitments

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[2]The six gases covered by the Protocol are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6). The most prominent of these, and the most pervasive in human economic activity is carbon dioxide, produced when wood or fossil fuels such as oil, coal, and gas are burned.

[3]See CRS Report 98-235 ENR, *Reducing Greenhouse Gases: How Much from What Baseline?*

in this Protocol, and continued to oppose emissions limitation commitments by non-Annex I countries. The negotiations concluded without such commitments, and the United States indicated that it will not submit the Protocol for Senate consideration—and therefore will not ratify it—until subsequent negotiations are held and meaningful commitments are made by developing countries. The next meeting of the Parties will be in November 1998 in Buenos Aires, Argentina, and may provide the first formal opportunity for this issue to be revisited, although it is not clear yet whether or how it would be put on the agenda for that meeting.

The Protocol does call on all Parties—developed and developing—to take a number of steps to formulate national and regional programs to improve "local emission factors," activity data, models, and national inventories of greenhouse gas emissions and sinks that remove these gases from the atmosphere. All Parties are also committed to formulate, publish, and update climate change mitigation and adaptation measures, and to cooperate in promotion and transfer of environmentally sound technologies and in scientific and technical research on the climate system.

Emissions Trading and Joint Implementation. Emissions trading, in which a Party included in Annex I "may transfer to, or acquire from, any other such Party emission reduction units resulting from projects aimed at reducing anthropogenic emissions by sources or enhancing anthropogenic removals by sinks of greenhouse gases" for the purpose of meeting its commitments under the treaty, is allowed and outlined in Article 6, with several provisos. Among the provisos is the requirement that such trading "shall be supplemental to domestic actions." The purpose of this proviso is to make it clear that a nation cannot entirely fulfill its responsibility to reduce domestic emissions by relying primarily on emissions trading or joint implementation to meet its targets. A number of specific issues related to the rules on how joint implementation and emissions trading will work are to be negotiated and resolved in subsequent meetings, as these issues are clarified and identified. In the months since the Protocol was completed, it has become increasingly clear that this is an extremely complex issue, and an emissions trading system is not likely to be designed and implemented quickly.

A major development is the establishment of a "clean development mechanism" (CDM), through which joint implementation between developed and developing countries would occur. The United States had pushed hard for joint implementation, and early proposals were formulated with the expectation that "JI" projects would be primarily bilateral. Instead, negotiations resulted in agreement to establish the clean development mechanism to which developed Annex I countries can contribute financially, and developing non-Annex I countries can benefit from financing for approved project activities; Annex I countries can then use certified emission reductions from such projects to contribute to their compliance with part of their emission limitation commitment. Emissions reductions achieved through this mechanism can begin in the year 2000 to count toward compliance in the first commitment period (2008-2012). Again, proposals on how this mechanism will operate will be developed and, presumably, discussed at the November 1998 Conference of the Parties. Like emissions trading, making the CDM operational appears likely to be a protracted and difficult process, given the increasing number of complexities emerging from the on-going work and discussions on how the CDM might work.

Issues for Congress

Ratification. For the United States to ratify the Protocol, the treaty must be submitted to the U.S. Senate for advice and consent. Ratification requires a two-thirds majority vote in the Senate for approval. Unless the United States ratifies the treaty, it will not be subject to its terms and obligations. President Clinton has voiced strong support for the Kyoto Protocol, and the United States is expected to sign it, although it is not clear when. However, in recognition of the opposition expressed in the Senate by S.Res.98, which passed 95-0, to a Protocol that does not include requirements for emissions limitations by developing countries, the President has indicated that he will not submit the treaty to the Senate for advice and consent until additional negotiations have provided for meaningful developing country participation. The next Conference of the Parties that would offer an opportunity to make such provisions will be in November 1998 in Buenos Aires. Thus it seems unlikely that the treaty will be submitted to the Senate until after that time.

Oversight. Both the House and Senate sent delegations of Members to serve as observers on the U.S. delegation to the Kyoto meeting. Supporters and opponents of the Protocol were included in these delegations. A number of committees have held hearings on the implications of the Protocol for the United States, its economy, energy prices, impacts on climate change, and other related issues.[4] While the Administration has stated that it believes the treaty can be implemented without harm to the U.S. economy, and without imposing additional taxes, a number of questions related to how its goals can be achieved are likely to arise in hearings during the year ahead.

Legislation. When a treaty is sent to the Senate for consideration, legislation that might be required for its implementation is also typically sent to the Congress. Such legislation is not likely in the near future, certainly not until the end of 1998, or until the treaty is sent to the Senate. However, the President's proposal on climate change, announced in October, included, among other things, a $5 billion package of tax credits and spending on research and development over 5 years to encourage energy efficiency and development of new lower emission technologies. In the President's budget proposals, he offered an initiative over multiple years of $6.3 billion dollars for research and development and some possible tax incentives. A number of legislative proposals—including bills, resolutions, and provisions in several appropriations bills—express concerns related to the Kyoto Protocol. Many of these would limit activities of the U.S. government that might be seen to advance the goals of the Kyoto Protocol prior to its consideration by the Senate.[5]

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[4]Congressional hearings are discussed in the CRS electronic briefing book on Global Climate Change at http://thomas.loc.gov/brbk/html/ebgcccon.html

[5]See CRS Issue Brief 89005: Global Climate Change. Another source for a listing of legislation and its status, and other information about the Kyoto Protocol and other climate change concerns and reports, is the CRS electronic briefing book on Global Climate Change on the CRS Home Page at: http://thomas.loc.gov/brbk/html/ebgcctop.html

General Accounting Office (GAO) Documents

United States General Accounting Office

GAO

Report to Congressional Committees

June 1997

GLOBAL WARMING

Information on the Results of Four of EPA's Voluntary Climate Change Programs

GAO/RCED-97-163

GAO

United States
General Accounting Office
Washington, D.C. 20548

Resources, Community, and
Economic Development Division

B-276994

June 30, 1997

The Honorable Christopher S. Bond
Chairman, Subcommittee on VA, HUD,
and Independent Agencies
Committee on Appropriations
United States Senate

The Honorable Jerry Lewis
Chairman, Subcommittee on VA, HUD,
and Independent Agencies
Committee on Appropriations
House of Representatives

Increasing emissions of carbon dioxide, methane, and other heat-trapping greenhouse gases generated by human activity are believed to contribute to global warming. In an effort to reduce greenhouse gas emissions, the United States issued its Climate Change Action Plan (CCAP) in October 1993. The plan was designed to reduce greenhouse gas emissions primarily through voluntary efforts by companies, state and local governments, and other organizations. The Environmental Protection Agency (EPA) is responsible for 20 CCAP programs. The Department of Energy and other federal agencies are responsible for other CCAP programs.

Because of your concerns about the effectiveness of the climate change programs, you asked us to determine (1) what EPA has done to ensure that the greenhouse gas reductions it reports reflect only the results of its efforts, as opposed to other factors, and (2) whether EPA's projected reductions are consistent with experience to date. As agreed with your offices, we focused our review on four CCAP programs, which are designed to reduce emissions of various greenhouse gases through work with different kinds of organizations. These four programs account for about one-third of EPA's funding for CCAP.

Specifically, the Green Lights Program primarily encourages businesses and other organizations to install energy-efficient lighting in their buildings in order to reduce the use of electricity and the emission of carbon dioxide produced by generating electricity. The Coalbed Methane Outreach Program encourages coal mining companies to capture and use, as an energy source, methane that would otherwise be vented to the atmosphere. To reduce greenhouse gas emissions from manufacturing, transporting, and disposing of materials, the Source Reduction and Recycling Program encourages businesses to reduce the amount of solid waste they generate and to increase the amount of waste they recycle. The State and Local Outreach Program helps state and local governments understand the sources of and possible solutions to global warming and also supports selected demonstration projects.

Results in Brief

For two of the four CCAP programs we reviewed, EPA adjusted the reductions in greenhouse gas emissions it had reported to account only for the effects of its efforts; for the other two programs, it did not adjust the reported reductions. Specifically, for the Coalbed Methane Outreach and Source Reduction and Recycling programs, EPA determined that nonprogram factors accounted for some of the reported reductions and, therefore, adjusted those reductions. For the Green Lights Program, EPA officials said that some reported reductions were probably the result of nonprogram factors, but they did not attempt to quantify the extent of the nonprogram factors because they believe it is not possible to do so. They said that any reductions resulting from nonprogram factors would likely be counterbalanced by reductions that they believe are attributable to the program but were not reported to EPA because the organizations did not participate in the program. Finally, for the State and Local Outreach Program, EPA did not attempt to determine whether some of the reported reductions resulted from nonprogram factors, although program officials said they tried to eliminate double-counting where reductions might be the result of other CCAP programs. EPA officials said they limited their efforts to quantify how much of the reported reductions resulted only from the effects of EPA's programs because it is difficult to make such an assessment, especially in the early stages of the programs' development.

EPA's projections of future reductions in greenhouse gases are not consistent with experience to date for three of the four programs but are consistent for the fourth program. For the Green Lights and Source Reduction and Recycling programs, the projected reductions are based on an assumption that the participants will, respectively, upgrade a larger proportion of their space and reduce waste at the source more in the future than they have thus far. For the State and Local Outreach Program, the projections assume that one key project will increase its impact, even though there are questions about the basis for the reductions reported thus far. Finally, for the Coalbed Methane Outreach Program, the projected reductions are consistent with experience to date.

Background

According to the Intergovernmental Panel on Climate Change, climate models project an increase in the earth's average surface temperature of between about two and six degrees Fahrenheit in the next century as a result of increasing emissions of greenhouse gases.[1] Furthermore, the panel reported in 1995, such increases could lead to floods, droughts, and other harmful changes in ecosystems. To address concerns about the possibility of global climate change, in May 1992 the United States and other countries signed the United Nations Framework Convention on Climate Change. As part of the Convention, the United States and other developed countries agreed to establish policies and measures with the aim of returning their greenhouse gas emissions to 1990 levels by 2000. In fulfilling its obligations under the Convention, the United States developed CCAP, whose goal is to reduce emissions by 109 million metric tons of carbon equivalent (MMTCE), from the projected 2000 level of 1,568 MMTCE to 1,459 MMTCE, slightly below the 1990 emissions level.[2]

EPA's 20 CCAP programs are generally designed to provide the information and tools to encourage the participants to voluntarily undertake changes that will reduce emissions of greenhouse gases whenever the changes make economic sense. Also, some programs are designed to overcome the institutional barriers that have traditionally prevented organizations from taking action.[3] The Congress appropriated about $86 million for EPA's CCAP programs for fiscal year 1997; EPA requested $149 million for these programs in fiscal year 1998.

For this review, we selected four programs because (1) they are involved with different greenhouse gases and different kinds of organizations, (2) each accounts for a substantial proportion of EPA's CCAP funding, and

[1]The panel was established in 1988 by the United Nations Environment Programme and the World Meteorological Organization to assess scientific and technical information about climatic change. See Working Group II Second Assessment Report: Summary for Policymakers: Impacts, Adaptation and Mitigation Options, Intergovernmental Panel on Climate Change, Working Group II, Technical Support Unit, Oct. 20, 1995. For additional information on the issue of global warming, see Global Warming: Difficulties Assessing Countries' Progress Stabilizing Emissions of Greenhouse Gases (GAO/RCED-96-188, Sept. 4, 1996.)

[2]Greenhouse gases have varied effects on the atmosphere as measured by their global warming potentials. These global warming potentials are applied to emissions to arrive at a common measure for the greenhouse gases; the measure is expressed in million metric tons of carbon equivalent.

[3]According to a 1992 report by the Office of Technology Assessment, there are several reasons why energy-efficient technologies are not used more often in buildings. These reasons include the following: (1) There is often a separation between those who purchase energy-using equipment (for example, building owners) and those who pay to operate the equipment (building tenants). (2) Because energy costs are relatively low in comparison to total operating costs, those concerned with cost reduction often focus elsewhere. (3) Energy efficiency is often misperceived as requiring discomfort or sacrifice, limiting its appeal. See Building Energy Efficiency, ch. 3, Office of Technology Assessment (OTA-E-518, May 1992).

(3) each is credited by EPA as substantially reducing greenhouse gas emissions. Appendix I provides funding levels, the number of participants, and other information about each program.

The Green Lights Program is designed to encourage organizations to voluntarily adopt energy-efficient lighting technologies, such as compact fluorescent light bulbs and electronic ballasts. EPA provides information intended to encourage the adoption of these technologies. The Source Reduction and Recycling Program is designed to reduce the volume of solid waste produced and sent to landfills. Under the program's WasteWise element,[4] EPA signs up businesses that agree to voluntarily decrease the amount of waste they generate and to increase the amount of waste they recycle. Under the program's Unit-Based Pricing element, local communities agree to charge residents for waste disposal on the basis of the amount of waste they generate.

The Coalbed Methane Outreach Program is designed to encourage coal mines and related industries to recover and use methane that would otherwise be emitted. The State and Local Outreach Program is a foundation program, designed primarily to raise awareness about climate change and provide technical support to state and local agencies and nonprofit organizations in analyzing and developing cost-effective response strategies, not to achieve short-term reductions in greenhouse gas emissions. The program also funds demonstration projects designed to test innovative strategies for reducing emissions and examine the impact of climate change on the states.

EPA establishes annual program targets for the programs, such as the volume of reductions in greenhouse gases (except for foundation programs, as noted above) and the number of participants. It tracks progress against these targets, relying primarily on reports from the programs' participants. However, EPA does not independently verify these reported reductions.

[4]EPA refers to it as WasteWi$e.

Greenhouse Gas Reductions Reported by EPA Are Not Limited to Program Effects in Two of the Four CCAP Programs We Examined

Efforts to improve energy efficiency, increase recycling, and achieve related goals have been under way for years. These long-standing efforts make it difficult to measure the programs' "net" reductions—those that result only from CCAP programs—as compared with total, or "gross," reductions—those that result from CCAP programs as well as from other, nonprogram factors. EPA officials told us that measuring the net reductions that are strictly due to the results of CCAP efforts is difficult.[5]

Green Lights Program

According to EPA, 2,308 organizations were participating in the Green Lights Program as of February 1997. These organizations committed to upgrade the lighting in 6 billion square feet of floorspace, about 9 percent of the national total, according to EPA. Through fiscal year 1996, Green Lights participants reported upgrading the lighting in 1.3 billion square feet of floorspace, resulting in greenhouse gas reductions of 0.6 MMTCE. Although some of the reported reductions may be the result of influences from outside of the Green Lights Program, EPA did not attempt to measure the program's "net" benefits. Officials said that they believed that any reductions that resulted from other factors were likely offset by the reductions achieved by the nonparticipating organizations that were influenced by the program but not reported to EPA.

According to the representatives of seven former participants we spoke with, the program had a positive impact on these organizations' efforts to achieve energy savings from lighting technology. When we interviewed officials at these organizations that had completed their participation in the Green Lights Program, representatives of all seven said that they were pleased with the program. For example, some representatives said that they viewed the data provided by EPA on the benefits of specific lighting technologies as being valuable and objective.

The reductions reported by EPA could be overstated if some Green Lights participants undertook at least some of their lighting upgrades because of nonprogram factors. Four factors suggest that some upgrades were made because of nonprogram factors.

First, according to a 1992 survey of commercial buildings, a substantial amount of floorspace was upgraded before the Green Lights Program was

[5]According to EPA officials, in a forthcoming report the administration will provide information on its estimates of the net greenhouse gas reductions resulting from the climate change programs. The report is scheduled to be issued in July 1997.

well established. The national survey of commercial buildings was conducted by the Department of Energy's Energy Information Administration (EIA).[6] The survey found that 43 percent of commercial floorspace had lighting conservation features (such as occupancy sensors and time clocks) and that 22 percent of the floorspace had undergone an energy audit (which can identify opportunities for saving energy) in the previous 5 years.

Second, financial incentives that were available during the early to mid-1990s may have induced some organizations to install energy-efficient lighting. Officials of the Edison Electric Institute, an electric utility trade group, estimated that 80 to 90 percent of its members offered financial incentives during that time period to encourage their customers to install more energy-efficient lighting. By offsetting some of the costs of lighting upgrades, such assistance provides an incentive to adopt energy-efficient lighting. In fact, Green Lights participants reported to EPA that they had received $143 million in such rebates through fiscal year 1996.

Third, some of the reductions attributed to the Green Lights Program were achieved by companies involved with lighting products, which could be expected to install energy-efficient lighting without the program. Of the 2,308 Green Lights participants, 593, or about one-quarter, were classified as "allies," that is, companies that manufacture, sell, and install lighting products. The reductions reported by these companies account for about 6 percent of the program's total. However, such companies could be expected to install energy-efficient lighting even without the Green Lights Program, given their knowledge of the benefits of this technology.

Finally, most of the representatives of organizations we spoke with about lighting upgrades, some of whom had participated and others who had not, told us that they would likely have made some of the upgrades without the program. When we spoke with the representatives of seven organizations that had completed their affiliation with the program, five of the seven stated that they would have done some or all of the upgrades without the program; the other two stated that they would not have done the upgrades without the program. In addition, we spoke with representatives of two major national corporations that did not participate in the program. Both companies told us that they had undertaken major lighting upgrades in the past few years without EPA's assistance.

[6] This survey was conducted shortly after the Green Lights Program was implemented. See Commercial Building Characteristics 1992, pp. 9-16, Energy Information Administration (DOE/EIA-0246(92), Apr. 1994).

Green Lights Program officials noted that they did not attempt to offset the reported reductions that may have been attributable to these other factors because they believe the program has offsetting impacts above and beyond the reductions reported by the participating organizations. For example, they noted several instances of nonparticipating companies that they believe undertook lighting actions as a result of information furnished by the Green Lights Program. However, they said they had not attempted to quantify the extent of the uncounted reductions by nonparticipants.

State and Local Outreach Program

According to EPA, 29 states and Puerto Rico have conducted inventories of their greenhouse gas emissions, 42 cities are developing action plans, and 7 demonstration projects have been selected for evaluation. Program officials said that although the program does not have a greenhouse gas reduction goal, it resulted in a reduction of 0.8 MMTCE in 1996.

Most of the reduction, about 0.7 MMTCE, was attributed to one demonstration project, called the Planet Protection Center. The main goal of this joint project between EPA and the approximately 46,000-member National Retail Hardware Association was to reduce residential energy use by promoting energy-efficient heating, lighting, and plumbing products. The participating retailers received materials to use in their stores to inform shoppers and salespeople, at the point of sale, about the benefits of buying energy-saving products. EPA officials said they initially estimated that 8 million households could reduce their energy consumption by an average of 10 percent because of the program. They said that to account for the possibility that market penetration might be less than 10 percent, as well as purchases that might have been made anyway, they halved the initial estimate.[7] The result of these adjustments was an estimate that 8 million households did reduce their energy consumption by an average of 5 percent each.

Studies by an EPA contractor and the hardware association raised questions about the link between the program's activities and the reported reductions, as did our analysis of data in the hardware association's study. First, the EPA contractor that analyzed the data on the project's effects said that there was no concrete estimate of the project's impact because, among other reasons, of the difficulty of collecting sales data and a seeming lack of methods for reporting progress in greenhouse gas

[7] Although program officials said they adjusted the estimated reductions, in part, because some purchases might have been made without the program, we found no analytical basis for either the initial estimate or the adjustment to it.

emissions (which would result from reduced energy consumption).[8] Second, the hardware association's 1995 study of the project's results found no overall difference in sales between the participating retailers and a control group of nonparticipants it surveyed, although it cautioned that the number of retailers responding was too small to be statistically significant.[9] The study found that about one-third of the participating retailers who responded said they featured energy- and water-conserving products from time to time without the project. For this report, we analyzed certain data presented in the association's study, including sales data for 31 energy- and water-saving product lines. According to data from the responding retailers, sales at the nonparticipating retailers increased more than sales at the participating retailers for 17 of the product lines and less for the other 14 product lines.

Source Reduction and Recycling Program

Although the Source Reduction and Recycling Program has two elements—WasteWise and Unit-Based Pricing—EPA attributed virtually all of the program's results to WasteWise. According to EPA, 513 companies were participating in WasteWise as of March 1997. EPA reported reductions from WasteWise of 0.8 to 2.3 MMTCE in fiscal year 1995—the most recent year for which it calculated greenhouse gas reductions. As with energy efficiency measures, the trends over the past few years indicate a general movement toward increased recycling. Recognizing that recycling exists outside of the program, EPA asks the WasteWise participants to report separately on recycling associated with the program and general recycling efforts. EPA officials explained that they compile the participants' reports and check them for general reasonableness. However, they do not make any further adjustments.

When we spoke with seven WasteWise participants about their experience, six of them said they were pleased with the program, generally because they appreciated the free information provided on recycling and reducing wastes. While all six also said they were likely or somewhat likely to have made some of the improvements without the program, two said that they accelerated their actions because of the program. The seventh participant said his company was already taking all the steps recommended by the program.

[8] "Planet Protection Center Program: Presentation and Discussion of Emissions Reductions Results," ICF, Inc. (1996).

[9] Environmental Merchandising and Advertising/Promotion in the Retail Hardware/Home Improvement Industry, National Retail Hardware Association (Indianapolis, IN: Aug. 1995).

The range in estimated reductions attributable to the WasteWise element is largely the result of incomplete reporting by the participants. For fiscal year 1995, less than half of the WasteWise participants reported their program accomplishments to EPA. The low-end estimate (0.8 MMTCE) was based on the amounts reduced and recycled by the reporting participants. The high-end estimate (2.3 MMTCE) was based on program officials' judgments that (1) some of the nonreporting participants also reduced their wastes and recycled and (2) the nonreporting participants who reduced and recycled did as much, on average, as did the reporting participants.

Coalbed Methane Outreach Program

According to EPA, as of February 1997, 13 projects had been started under the Coalbed Methane Outreach Program. On the basis of the data on methane reported by the coal companies, EPA reported gross reductions of 2.7 MMTCE in 1996.

EPA officials estimated that 60 percent of the gross reductions were the result of nonprogram factors and that the program achieved net reductions of 1.1 MMTCE in 1996. The primary nonprogram factor is the Energy Policy Act of 1992, which helped remove a barrier to the capture of coalbed methane. EPA officials said they calculated the 60-percent factor by estimating the increase in the amount of methane captured as a result of their program over the amount that would have been captured as a result of the 1992 act without their program.

Specifically, certain provisions of the 1992 act were intended to deal with the possibility that adjacent landowners could contest the ownership of coalbed methane, which could discourage coal companies from capturing that methane. To help overcome this barrier, the act provided that the Department of the Interior would implement a program, in certain states, relating to those entities claiming an ownership interest in a particular unit of coalbed methane. Under the program, these entities would be required to arrange for an escrow account to be established and the proceeds from the sales of such coalbed methane would be placed into that account. Ultimately, the proceeds would be distributed after a final legal determination of ownership interest.[10]

In addition, program officials said that they claimed credit for the reductions in coalbed methane only if the coalbeds were being mined.

[10]Such programs were to be established in states that, among other things, have disputes about the ownership of coalbed methane and that do not have programs promoting the permitting, drilling, and production of coalbed methane.

Thus, the methane captured from wells drilled into coalbeds was not counted if the coal was not yet being mined. That methane could be counted later, when the coalbed was being actively mined.

Projected Greenhouse Gas Reductions Exceed Historical Results for Three of the Four CCAP Programs We Examined

EPA's projections of future greenhouse gas reductions depend on a number of assumptions, such as the number of participants, the extent to which these participants will act to decrease emissions, and the extent to which the reductions are linked to the program's efforts. As discussed in detail below, for the Green Lights and Source Reduction and Recycling Programs, the reductions projected for 2000 are based on a level of performance by the participating organizations that exceeds the programs' results to date. EPA officials said they believe that the performance of many programs will improve over time, in part because of their experience and because of better targeting of the programs.

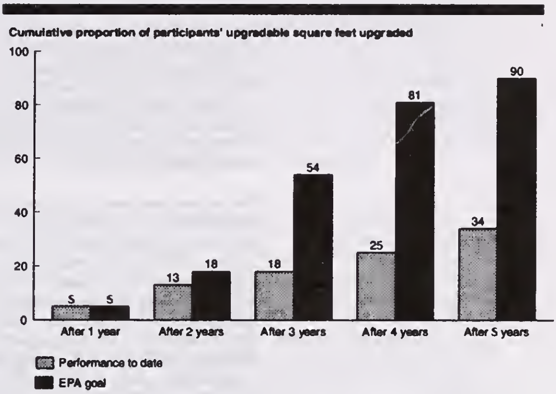
For the State and Local Outreach Program, about one-half of the projected reductions of 1.7 MMTCE for 2000 are attributed to the Planet Protection Center project. In the previous section, we noted that there are questions about whether some of the project's reported greenhouse gas reductions were the result of nonprogram factors; such questions would also apply to its projected reductions. For the Coalbed Methane Outreach Program, the projected reductions are consistent with experience to date, and EPA continues to attribute about 60 percent of the gross reductions to the 1992 Energy Policy Act. Thus, the estimated gross reductions of 6.1 MMTCE in 2000 are reduced to net reductions of 2.6 MMTCE as a result of the program.

Green Lights Program

EPA estimates that the Green Lights Program will result in 3.9 MMTCE in annual greenhouse gas reductions in 2000; the estimate is based on several assumptions, including the amount of floorspace that will be upgraded with new lighting technology. When they join the Green Lights Program, the participants agree to survey the floorspace in all of their facilities and to upgrade 90 percent of the space which is considered upgradable and for which it is cost-effective to do so.

EPA established year-by-year goals, leading up to the 90-percent level after 5 years. For example, the goal is to upgrade 18 percent after 2 years and 54 percent after 3 years. In addition, EPA tracks the participants' accomplishments relative to these goals. According to EPA, the organizations that participated in the program for 5 years had upgraded only 34 percent of their upgradable floor space within that time period. (See fig. 1.)

Figure 1: The Results of the Green Lights Program for the First 5 Years Were Below EPA's Goals



Source: EPA's data.

Program officials believe that in the future the participants will be able to achieve the 90-percent level because EPA has increased its level of support for the participants. For example, they are contacting participants more often to see if there is additional information that EPA can provide or if there are particular impediments that EPA can help them overcome. Program officials noted that the companies joining in 1995 exceeded the 18-percent goal established for upgrades through the second year of program participation. However, for participants joining in the 4 earlier years (1991-94), EPA's data show that the participants did not meet the 18-percent goal after participating for 2 years.

It may be difficult for EPA to achieve its Green Lights goals for two other reasons. The first reason relates to electricity prices. The Energy Information Administration projects that the average price of electricity will decline over the next 20 years by 0.6 percent per year after inflation, which would tend to make lighting investments less attractive. Moreover, the widespread discussion of deregulating electricity at the retail level, and the possible substantial cost decreases for larger users, create uncertainty about future electricity prices. An EPA program official noted that lighting investments are highly cost-effective and that any marginal decrease in electricity prices should make little difference to organizations that have joined the program. However, we note that decreasing or uncertain prices could make lighting investments appear less attractive to prospective Green Lights participants.

The second reason relates to possible "self-selection" bias among the initial Green Lights participants. In this context, self-selection is the likelihood that the organizations that voluntarily join a program may have been most likely to undertake those activities even if there were no program. Self-selection bias is a concern in evaluating the effectiveness of voluntary energy-efficiency programs, according to a paper on evaluating such programs.[11] To the extent that the organizations most likely to upgrade were the ones that joined the program initially, it may be difficult for EPA to continue to recruit large numbers of organizations into the program. However, EPA officials said they believe that a continued education campaign, coupled with successful upgrades by businesses, will make recruitment easier.

Source Reduction and Recycling Program

EPA estimated that the program's WasteWise and Unit-Based Pricing elements would both achieve substantial reductions in 2000. For WasteWise, the reductions were estimated to range from 1.9 to 6.7 MMTCE. The lower estimate is based on the assumptions that a higher proportion of participants will reduce waste at the source and recycle in the future and that their average levels of source reduction will increase. Specifically, EPA assumes that the proportion of WasteWise participants that reduce waste will increase from 40 percent in 1995 to 90 percent in 2000 and that the proportion that recycle will increase from 75 percent in 1995 to 90 percent in 2000. Moreover, EPA assumes that the amount of waste reduced per participant will increase by 50 percent between 1995 and 2000. The higher level (6.7 MMTCE—more than three times the lower level)

[11] Gretchen B. Jordan and Darrell A. Beschen, "Planning for Evaluation of the U.S. Department of Energy's Energy Partnership/Climate Change Programs," presented at the 1995 International Energy Program Evaluation Conference, Chicago, IL (Aug. 1995).

is based on additional assumptions designed to adjust for the reductions that EPA believes were underreported in 1995.

For Unit-Based Pricing, EPA estimated in 1995 that it would achieve reductions of 2.2 MMTCE in greenhouse gases in 2000. This projected level was based on an assumption that 575 communities would adopt a unit-based pricing approach to waste disposal each year. However, EPA program officials later found that only 72 communities adopted unit-based pricing in 1995. Program officials believe that the lower results for 1995 were the result of underestimating the time needed for the communities to implement unit-based pricing. The officials said that they now have the tools to promote a much greater adoption of unit-based pricing and that enrollments in 1996 and 1997 increased substantially.

Agency Comments

We provided copies of a draft of this report to EPA for review and comment. We received responses from three EPA offices. We received a letter from the Director, Office of Atmospheric Programs, Office of Air and Radiation, whose office manages the Green Lights and Coalbed Methane Outreach programs. (App. II contains the complete text of his letter, along with our detailed responses.) We also obtained comments from the Director, Climate Policy and Programs Division, Office of Policy and Program Evaluation; and the Director, Municipal and Industrial Solid Waste Division, Office of Solid Waste and Emergency Response. The former office manages the State and Local Outreach Program, and both offices are involved in the Source Reduction and Recycling Program.

The Director, Office of Atmospheric Programs, discussed the difficulties of evaluating the effects of voluntary programs. Also, he said that the draft report inaccurately used EIA's survey data to suggest that EPA overstated the reductions achieved by the Green Lights Program. We believe that we used these data fairly. We cited them to demonstrate that some companies with commercial office space had undertaken energy audits and installed energy-efficient lighting by 1992, when the Green Lights Program was just beginning. We believe that the factors that induced companies to take such actions before 1992 would likely have continued beyond 1992 and may, in part, account for some companies' decisions to join the Green Lights Program and to undertake upgrades. However, as noted in the report, EPA's reported reductions did not account for nonprogram factors that may have induced Green Lights participants to undertake upgrades.

The Director, Office of Atmospheric Programs, also stated that the climate-change programs are improving over time and that he does not believe that the projected reductions are optimistic. We noted that the projections are not consistent with experience to date. It is possible that, with the improvements he mentioned, the programs could meet their goals for 2000.

The Director, Climate Policy and Programs Division, objected to our including the State and Local Outreach Program in this review because it is considered a foundation program. That is, the program is not primarily intended to achieve reductions in greenhouse gas emissions. Rather, it is intended, among other things, to motivate state and local officials to understand the rationale behind taking actions to reduce emissions. As noted in the report, we included the program because, according to EPA's data, it was responsible for substantial reductions in greenhouse gas emissions in 1996 and is projected to achieve even more substantial reductions in 2000.

The Director, Municipal and Solid Waste Division, as well as the other two directors who commented on the report, provided updated data and technical corrections, which we incorporated in the report as appropriate.

We conducted our review from September 1996 through June 1997 in accordance with generally accepted government auditing standards. See appendix III for the details of our scope and methodology.

As arranged with your offices, we plan no further distribution of this report until 15 days after the date of this letter unless you publicly announce the report's contents earlier. At that time, we will send copies to the appropriate congressional committees and the Administrator of EPA. We will also make copies available to others upon request. If you have any questions or need additional information, please call me at (202) 512-6111. Major contributors to this report are listed in appendix IV.

Peter F. Guerrero
Director, Environmental Protection
Issues

Contents

Abbreviations

CCAP	Climate Change Action Plan
EIA	Energy Information Administration
EPA	Environmental Protection Agency
GAO	General Accounting Office
MMTCE	million metric tons of carbon equivalent
OIG	Office of Inspector General

Appendix I

Participants, Funding, and Other Details About Four CCAP Programs

Dollars in millions

	Green Lights	Source Reduction and Recycling	Coalbed Methane Outreach	State and Local Outreach[a]
Targeted gas(es)	Carbon dioxide	Carbon dioxide and methane	Methane	Various
Type of participants	Businesses and governments	Businesses and local governments	Coal companies	States, territories, and local governments
Number of participants	2,308	513	13[b]	29 states, Puerto Rico, 42 cities
FY 1996 funding	$20.1	$2.9	$1.7	$5.3
Greenhouse gas reductions through FY 1996 (MMTCE)	0 6	0.9-2.4[c]	2.7[d]	0.8
Greenhouse gas reductions estimated in 2000 (MMTCE)	3.9	4.1-8.9	6.1[d]	1.7

[a]The State and Local Outreach Program was primarily intended to help lay a foundation for greenhouse gas emission reductions beyond 2000, not to achieve greenhouse gas reductions by 2000. However, according to EPA, the program did achieve substantial reductions through 1996 and is expected to achieve even greater reductions in 2000.

[b]Represents number of projects.

[c]Data for the Source Reduction and Recycling Program are for fiscal year 1995.

[d]Represents "gross" reductions "Net" reductions are estimated to be about 40 percent of the "gross" reductions—1.1 MMTCE in 1996 and 2 6 MMTCE in 2000

Appendix II

Comments From the Environmental Protection Agency

Note: GAO comments supplementing those in the report text appear at the end of this appendix

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

JUN 9 1997

OFFICE OF
AIR AND RADIATION

Mr. Peter F. Guerrero
Director
Environmental Protection Issues
U.S. General Accounting Office
Washington, D.C. 20548

Dear Mr. Guerrero:

See comment 1.

I appreciate the opportunity to review and comment upon the draft GAO Report, Information on Results of Four EPA Voluntary Climate Change Programs. My first comment is that the initial scope of your review, as presented in a Memorandum from GAO to EPA (August 27, 1996), was a much broader review of the Climate Change Action Plan (CCAP) programs than what you refer to in the Report. This original scope included first a determination of "the types of performance measures EPA has developed for CCAP programs." It is therefore disappointing that the draft Report fails to mention EPA's significant accomplishments in measuring, evaluating, and reporting on the progress of CCAP programs.

EPA has developed a successful and extensive system of performance measures and program evaluation. EPA devotes considerable effort to obtaining the best possible information upon which to evaluate the programs. For example, EPA reports the results of the Green Lights program based exclusively on detailed reports submitted by the program's partners on over 14,000 completed projects around the country. These efforts and the efforts of other programs have provided maximum accountability and valuable information for program development. EPA's performance measures have been reviewed in detail by your staff and are largely the basis for GAO's Report.

See comment 2.

I would like to draw your attention to a recent report by the EPA Office of the Inspector General (OIG). The OIG recently completed a review of some of EPA's important CCAP programs (Risk Reduction Through Voluntary Programs, Audit Report No. E1KAF6-05-0080-7100130, 3/19/97). The OIG found that the programs "effectively estimated the impact their activities had on reducing risks to health and the environment," and that the programs "used good management practices," including good planning, progress evaluation, and program adjustment. The report concluded that "future voluntary programs could benefit from using similar measurement techniques." The revised, narrow focus presented in GAO's draft Report does not sufficiently recognize the high standard of accountability that EPA uses in evaluating and reporting on its CCAP programs.

See comment 3

While the GAO draft Report does include important issues regarding measuring program success, they are ones that are difficult for all market transformation efforts. EPA has always recognized that there are many difficult analytical issues in evaluating the success of voluntary, market-based programs, and has therefore conservatively estimated the impacts of the CCAP programs. EPA has openly discussed these issues with your staff. There is some uncertainty, for example, in isolating the effects of a program such as Green Lights from other factors within the market. This uncertainty can work in either direction -- leading programs to overestimate or underestimate results -- depending on the measurement techniques used. In order to address this uncertainty, EPA has either adjusted a program's numbers or chosen methodologies that would likely underestimate the net impact of a program. For two of the four programs examined, GAO points to the absence of specific "adjustments" as, in itself, a significant conclusion. For some programs, however, EPA has instead decided to use a generally conservative approach rather than make arbitrary "adjustments" where sufficient data is not available. GAO should recognize in the final Report that there are different means of handling uncertainty, that EPA has addressed these issues in a reasonable manner, and that EPA does not overstate its program accomplishments.

For example, the Green Lights program's reported accomplishments likely significantly underestimates the actual accomplishments for a number of reasons. The Green Lights program is an informational program that generates broad awareness and provides technical informational to everyone who is willing to use it, regardless of whether or not they join the program. EPA monitors the program's performance based exclusively on completed projects reported by those who join the program and fill out annual reports. EPA believes that this methodology is highly conservative. Although a majority of lighting technologies purchased today for buildings remain the least efficient technologies, there has nevertheless been substantial improvement in the market share of the more efficient technologies promoted by Green Lights since the program began in 1991 (based on U.S. Census manufacturing and sales data that we have shared with your staff). EPA is reporting only a fraction of this larger market improvement as being attributable to the accomplishments of the Green Lights program.

The true program impact of the Green Lights program is likely much larger than what EPA has been reporting to date, and EPA intends to study improved means of measuring this impact. We have provided your staff with evidence to support the many reasons that the Green Lights program estimates are conservative. The main reasons are summarized as follows:

(1) The impacts of Green Lights' efforts to generate awareness of cost-effective investment opportunities for energy efficiency are widely dispersed, with only a portion of those who make such investments joining the program.

(2) EPA widely distributes its important technical information on lighting. A large number of people who attend the Green Lights' lighting upgrade workshops, for example, do not belong to the program.

(3) Because partner reports are submitted once a year, there is up to a one-year time lag in measuring program performance. This is especially significant because the program's accomplishments are now rapidly accelerating; 40 percent of the program's current accomplishments have been generated by upgrades that were reported within the last year, despite the fact that the program is 6 years old. This alone suggests that true program impact is underestimated by 20% or more because of the reporting delay.

(4) Not all partners complete and submit reports once they've completed lighting upgrades, resulting in under-reporting of partners' true accomplishments. EPA is studying alternative methods for information collection.

See comment 4

The GAO Report raises some of the many important issues regarding measuring program results that EPA attempts to address in evaluating its CCAP programs. As the programs' market impact increases and better information becomes available, we intend to better isolate the broader market impact of the programs, rather than relying exclusively on techniques such as measuring direct program participation. EPA intends to study the issue further this coming year. EPA does not believe that asking a few partners retrospectively whether or not they would have completed the upgrade is an appropriate means of completing a study. The intent of the Green Lights and other CCAP programs is to generate awareness and provide the support and technical information needed to allow partners to invest in profitable energy efficiency. After realizing extremely high returns on their investments, while improving the quality of their lighting, it is not surprising that partners' hindsight includes "20/20" vision. We view this as a major accomplishment -- making energy efficiency investments part of the normal business practices is the ultimate measure of program success. However, we know from experience, and from the continued inefficient practices of a majority of businesses today, that getting partners to devote their capital to non-traditional investments, such as facility energy, is anything but normal business practice. This is also widely documented outside of our own program experience (including the Office of Technology Assessment study referenced in the GAO Report). Although GAO has not shared with us the names of the companies that it finally interviewed, I encourage you to discuss with my staff that supports these partners the considerable efforts it took to turn each of those partners into a success story.

See comment 5

With regard to estimating the future impact of the programs, EPA does assume that, for some programs, current and future partners will do better than initial partners in the program. For example, the Green Lights program expects that partners who have recently joined the program will do better in meeting their full commitments than the partners that joined in the first year (i.e., the partners that have been in the program for the full five years of the commitment). As you acknowledge in the Report, EPA has demonstrated that this improvement is already occurring. After two years in the program, for example, partners that joined ion 1995 have done considerably better than the first year's partners, achieving four times the energy and pollution reductions (despite smaller commitments). This success has improved steadily since the beginning of the program, and current partners are well ahead of the program's targets. This is in part due to changes made in the program to improve partner support. EPA is pleased that the

3

programs are improving through time, and does not believe that the forecasted program impacts are optimistic. As mentioned previously, the program impact is increasing rapidly: 40 percent of the program's current accomplishments have been generated by upgrades that were reported within the last year, despite the fact that the program is 6 years old.

See comment 6

Finally, I would like to point out that the draft report inaccurately uses the Energy Information Administration's (EIA's) survey of commercial floorspace to suggest that EPA overstates the reductions achieved by the Green Lights program. The EIA survey is based on 1992 data. EPA only measures additional energy savings for the Green Lights program that would be above and beyond the pre-existing "conservation features" identified in EIA's survey. Also, as we have noted to you in the past, EIA has only asked respondents to indicate the presence of some energy conservation features in their buildings. They have not evaluated the effectiveness of these energy conservation features. In fact, EIA found that the energy intensities for buildings with conservation features, as defined by EIA, are "the same or even greater than the energy intensities of buildings without those features" (p. 11). In contrast, Green Lights program partners are, on average, reducing their lighting energy consumption by 48 percent through comprehensive lighting retrofits.

There are some additional numbers and references that appear somewhat inconsistent with information that we have provided to you. My staff is providing these clarifying comments separately.

Sincerely,

Paul M. Stolpman
Director
Office of Atmospheric Programs

The following are GAO's comments on the Environmental Protection Agency's letter dated June 9, 1997.

GAO Comments

1. When we began our work on this assignment, one of our objectives related to the types of performance measures used for EPA's climate change programs. As agreed with the requesters' offices, we did not pursue this issue in detail. However, our report does provide information about EPA's performance targets, collection of data from participants, and related matters.

2. As part of our review, we considered the Office of the Inspector General's (OIG) report. The OIG's report differs somewhat from our report in terms of both scope and objectives. Whereas we reviewed only voluntary climate change programs, the OIG reviewed voluntary climate change programs, as well as the Radon Action Program, which is not related to climate change. In terms of objectives, we focused exclusively on the reported and projected reductions of greenhouse gas emissions for the four climate change programs. The OIG's objectives were to determine (1) the management practices that worked well and areas in which improvements are needed and (2) whether voluntary programs achieve environmental benefits. Although the second OIG objective sounds similar to our objectives, the OIG did not attempt to determine whether nonprogram factors may account for some of the reductions reported by EPA. The OIG's report states that "it is difficult to directly attribute changes in the environment to a particular statute, regulation, or program." For these reasons, we believe that the OIG's report is not directly comparable to ours, and we therefore did not change our report to address this comment.

3. EPA noted that measuring the success of programs to bring about change in specific markets is difficult. We agree. EPA characterized its approach in estimating the effects of its programs as "conservative" and stated that the "true program impact of the Green Lights program is likely much larger" than the reductions reported by EPA. While EPA states that the program's total impact is likely to be much larger than its reported impact, this can be true only if the unreported reductions that are due to the program are larger than the reported reductions that are due to nonprogram factors. However, EPA has not attempted to measure either of these indicators.

With respect to the issue of evaluating the net effect of the Green Lights Program, we are pleased to learn that EPA "intends to study improved means of measuring" the program's total impact. Successful completion of this study and implementation of its suggestions should help ensure that, in the future, there will be more reliable information on the program's gross and net impacts.

4. EPA raises questions about both the purpose and the results of our discussions with the organizations that participated in the Green Lights Program. The purpose was to ask them about their experience with the program, including the extent to which the program contributed to their lighting upgrades. By contacting only those organizations that had participated successfully, we were dealing with a group that was likely to be relatively favorable toward the program. The result of the discussions was that, rather than exhibiting perfect hindsight, as EPA's response suggests, all gave credit to EPA for providing valuable and reliable information and for being responsible for some or all of their upgrades. We believe this information, along with the other information presented, supports the point that only some, but not all, of these organizations' upgrades were due to the program.

5. With respect to possible improvements in the program's effectiveness, we presented data from EPA on results through 2 years for organizations that joined in 1995 (the class of 1995). The future implications of this reported improvement are unclear for two reasons. First, we also noted that, unlike the four previous classes, the class of 1995 was the only one to meet EPA's goal of upgrading 18 percent of upgradable floorspace after 2 years. Second, the reason for the improvement is not clear. EPA claimed that its improved efforts accounted for the improvements. However, it is also possible that a change in reporting practices may have contributed to the reported improvement. Specifically, starting in 1993, organizations joining the program were permitted to claim credit for upgrades they had completed prior to joining the program. Initially, they were permitted to claim credit for upgrades made in the previous 12 months; later, they were permitted to claim credit for upgrades made in the previous 18 months. Thus, the larger reported results for the class of 1995 may, in part, reflect a change in reporting practices.

6. We cited the 1992 Energy Information Administration's survey data for the same reason we interviewed former participants (see comment 4). We wanted to see whether there was evidence that companies with commercial office space were undertaking energy audits and installing energy-efficient lighting independent of the Green Lights Program. The survey data confirmed that there was substantial activity in the years

before the program was established. If energy-efficient lighting was installed in some buildings before the program was established, we believe that energy-efficient lighting installed afterwards in other buildings may have been due, at least in part, to nonprogram factors.

Appendix III

Scope and Methodology

As agreed with your offices, of the Environmental Protection Agency's (EPA) 20 Climate Change Action Plan (CCAP) programs, we selected the following four for our review: Green Lights, Source Reduction and Recycling, Coalbed Methane Outreach, and State and Local Outreach. These four programs represent about one-third of EPA's CCAP funding and about one-third of the estimated greenhouse gas reductions planned by EPA for 2000—the year in which the action plan hoped to stabilize greenhouse gas emissions at about the 1990 level. Although the State and Local Outreach Program was not intended primarily to achieve reductions through 2000, we included it in our review because EPA reported that it did achieve substantial reductions through 1996 and was expected to achieve even greater reductions in 2000.

To address our objectives for all four programs, we met with EPA program officials for the four programs to discuss their reported program reductions and the steps they take to ensure that the reductions reflect the program's actions, rather than other factors. We also reviewed the reported results from the organizations that have joined the programs and the program offices' methods for calculating actual and planned greenhouse gas reductions. We also reviewed other available reports, from GAO and other organizations, on EPA's voluntary programs. In those cases where EPA adjusted reported or projected reductions (to remove the effects of nonprogram factors), we did not attempt to determine the reasonableness of those adjustments.

In addition, as noted below, we discussed the programs with selected current or former participants and nonparticipants. Although we tried to select a mix of organizations, in terms of size and geographic location, the organizations we contacted may not be representative of all such organizations. Finally, as noted below, we used other data sources.

For the Green Lights program, we interviewed officials at seven former participants, which had graduated from the program, about their motivations for joining the program and their experiences in the program. We picked these seven from a list of about 300 program graduates provided by EPA. The seven included small, medium, and large organizations, which are located in various regions of the country and are in different industries. Because program officials said they were concerned that our contacting current Green Lights participants might discourage participation, we did not contact any current participants. We also interviewed officials at two major corporations that were not participating in the program, to determine whether they had undertaken lighting upgrades. To review the extent of the lighting upgrades already under way, we reviewed the results of a 1992 Energy Information Administration survey on commercial buildings and energy-saving features. We also reviewed data provided by the Edison Electric Institute on electric utilities that sponsored energy-efficient lighting rebate programs.

For the Source Reduction and Recycling Program, we interviewed officials at seven current program participants about their motivations for joining the WasteWise component. We also reviewed EPA's March 1996 report, Characterization of Municipal Solid Waste in the United States: 1995 Update, to determine the historical trends in the recycling of waste. For the Coalbed Methane Program, we interviewed representatives from two coal mining companies about their motivation for joining the program and their satisfaction with EPA's efforts.

Appendix IV

Major Contributors to This Report

Resources, Community, and Economic Development Division	Philip L. Bartholomew James B. Hayward David Marwick Robert D. Wurster
Office of the General Counsel	Karen Keegan

United States General Accounting Office

GAO

Report to the Chairman, Committee on the Budget, House of Representatives

April 1998

DEPARTMENT OF ENERGY

Proposed Budget in Support of the President's Climate Change Technology Initiative

GAO/RCED-98-147

GAO

United States
General Accounting Office
Washington, D.C. 20548

Resources, Community, and
Economic Development Division

B-279612

April 10, 1998

The Honorable John R. Kasich
Chairman, Committee on the Budget
House of Representatives

Dear Mr. Chairman:

Increasingly, emissions of carbon dioxide and other heat-trapping "greenhouse gases" from energy production, industry, transportation, agriculture, and other human activities are becoming concentrated in the earth's atmosphere. Many scientists believe that the buildup of these gases is creating a greenhouse effect that will lead to global warming. Global climate changes could influence weather patterns, including shifts in precipitation patterns that could lead to flooding, changes in crop yields, and changes in ecosystems. In his State of the Union address, the President noted that the United States has agreed with other nations to reduce its greenhouse gas emissions through market forces, new technologies, and energy efficiency. In support of this agreement, the President proposed $6.3 billion over the next 5 years for the Climate Change Technology Initiative, which would fund research and development (R&D) and the deployment of new technologies to encourage energy efficiency, renewable energy, and technologies to reduce the amount of carbon dioxide emitted into the atmosphere, as well as provides tax incentives. The Department of Energy (DOE) is expected to implement the largest portion of this initiative through its programs and activities.

As requested, we are providing you with (1) information on how DOE plans to alter its climate change R&D spending from fiscal year 1998 to fiscal year 1999 and (2) our observations regarding funding for R&D, based on our previous work in this area. On March 12, 1998, we briefed your staff on the results of our work and agreed to provide you with this report summarizing our findings. (App. I provides our briefing materials.)

Results in Brief

DOE is proposing to increase its spending to about $1.06 billion for R&D in fiscal year 1999 to support the Climate Change Technology Initiative, a $331 million increase from funding in fiscal year 1998 for programs related to climate change. The $331 million increase as well as the remaining $729 million will continue to support and expand existing R&D programs in energy efficiency and renewable energy as well as other programs related to climate change. Total funding, according to DOE, will address multiple energy and environmental goals, including decreasing the United States' dependence on foreign oil, improving air quality, decreasing energy costs for consumers and businesses, increasing economic competitiveness, and cutting greenhouse gas emissions.

From reviewing our previous reports on R&D, we have drawn five common themes, stated here as questions, that the Congress may want to consider as it deliberates DOE's budget proposal: (1) Would the private sector do the research without federal funding?; (2) Will consumers buy the product?; (3) Do the benefits exceed the costs?; (4) Have efforts been coordinated?; and, (5) Have implementation concerns been addressed?

DOE's Climate Change R&D Funding

Overall, DOE is proposing to increase its budgetary authority of $729 million in fiscal year 1998 to about $1.06 billion for R&D in fiscal year 1999 in support of the Climate Change Technology Initiative. The $331 million increase in R&D funding will, according to DOE, expand the most promising R&D programs and accelerate the development of energy technologies in six organizations of the Department: Energy Efficiency, Renewable Energy, Fossil Energy, Nuclear Energy, Energy Research, and the Energy Information Administration. The largest increase in DOE's climate change R&D funding would occur in Energy Efficiency and Renewable Energy, where the combined fiscal year 1999 funding would be increased by about $261 million over the fiscal year 1998 level—from about $729 million to about $990 million. Increased R&D funding in these areas will, according to DOE, help to develop high-efficiency vehicles; alternative vehicle fuels, such as "biofuels" from plants or waste; more energy-efficient buildings; higher-efficiency industrial processes; and solar and wind systems; among other projects. DOE officials said that the use of these technologies will help to reduce carbon dioxide emissions into the atmosphere as well as satisfy other energy and environmental goals.

The remaining $70 million will increase funding in the other four organizations, with Fossil Energy and Energy Research receiving the next largest shares of about $30 million and $27 million, respectively. A key effort in fossil energy R&D will be the Department's Vision 21 Program, which will focus on combining several energy technologies into a single ultra-high-efficient system that is expected to reduce energy consumption and emissions. The increase for Energy Research will fund a broad range of basic scientific research focused on long-term solutions to climate change. Nuclear Energy and the Energy Information Administration will receive the remaining increase in funding.

Observations Regarding Federal R&D

According to DOE, it has historically supported a wide range of energy R&D in eight program areas—with funding of about $61.8 billion from 1978 through 1995.[1] As we have reported previously, while the amount of money spent on R&D is useful as a measure of how much research is being performed, it is not a good indication of the results of research.[2] From reviewing our previous reports, we have drawn the following five common themes, stated as questions, that may help the Congress consider DOE's proposed R&D budget:[3]

Would the private sector do the research without federal funding? Our work suggests federal R&D programs sometimes displace research that private industry may have done without government funding. For example, in our 1996 report on the Department of Commerce's Advanced Technology Program, we found that about 40 percent of the award recipients said they would have conducted the research without assistance from the program.[4]

Will consumers buy the product? One of the keys to successful research is that the resulting technology will be competitive in the marketplace. In our 1995 report on the United States Advanced Battery Consortium's development of batteries for electric vehicles, we found that, although the consortium may reach its technological midterm goals for the batteries, the vehicles that use them will be too expensive and will not perform well enough to compete with traditional automobiles. Moreover, members of the consortium from the automobile industry believed large subsidies would be needed to sell cars with midterm batteries. These members also doubted that vehicles with midterm batteries would achieve any significant market penetration.[5]

Do the benefits exceed the costs? Our previous work suggests the federal government has a mixed record in estimating the costs and benefits of federally funded R&D. In our 1996 review of DOE's Success Stories report, we noted that the Department had made valid claims about the benefits of

[1]This figure is in constant 1995 dollars.

[2]Measuring Performance: Strengths and Limitations of Research Indicators (GAO/RCED-97-91, Mar. 21, 1997).

[3]We do not intend our five questions as an assessment of DOE's performance in these areas.

[4]Measuring Performance: The Advanced Technology Program and Private-Sector Funding (GAO/RCED-96-47, Jan. 11, 1996).

[5]Electric Vehicles: Efforts to Complete Advanced Battery Will Require More Time and Funding (GAO/RCED-95-234, Aug. 17, 1995).

a few of the technologies. Some of these benefits may be substantial, but, in most cases, DOE did not state how much it spent developing the technologies or had problems with its analyses.[6]

Have efforts been coordinated? Ensuring that DOE's R&D is consistent with other federal R&D efforts and with its mission statement and strategic plan under the Government Performance and Results Act of 1993 is important in order for the Department to limit duplication and focus its funding effectively. Furthermore, because many of the Department's activities, such as the Partnership for a New Generation of Vehicles, cut across a number of other federal agencies, coordination with these agencies is essential.[7]

Have implementation concerns been addressed? Our past work has shown that agencies sometimes do not have the administrative structure needed to implement R&D projects effectively. In a 1995 report on unobligated funds in the Advanced Technology Program, we observed that, in fiscal year 1995, the funding and the planned number of awards for the program about doubled.[8] However, the National Institute of Standards and Technology (NIST), the agency that administers the program, did not increase its administrative staff at the same rate to make the awards. At the end of fiscal year 1995, NIST had not made all its planned awards and carried over a unobligated balance of $136.4 million.[9]

In response to our questions, DOE said that it carefully considers each of these questions when it formulates budget proposals. According to DOE, proposals that do not successfully answer these questions are not included in its budget request.

Scope and Methodology

We conducted our review from January 20, 1998, through March 1998 in accordance with generally accepted government auditing standards. We reviewed DOE's fiscal year 1998 estimated discretionary budget authority and compared it to the Department's proposed fiscal year 1999 budget for

[6] DOE's Success Stories Report (GAO/RCED-96-120R, Apr. 16, 1996).

[7] The Partnership for a New Generation of Vehicles is an industry-government cooperative partnership between Chrysler, Ford, and General Motors and 11 federal agencies or entities to (1) develop manufacturing techniques to reduce the time and cost of automotive development, (2) improve fuel efficiency and emissions performance, and (3) develop a vehicle with triple the fuel efficiency of today's midsize cars while maintaining or improving safety, performance, emissions, and price.

[8] NIST's Unobligated Funds (GAO/RCED-95-166R, May 4, 1995).

[9] NIST Carryover Balances (GAO/RCED-97-144R, Apr. 30, 1997).

the Climate Change Technology Initiative. We spoke with DOE officials in each of the major program divisions involved in the Initiative, including Energy Efficiency, Renewable Energy, Fossil Energy, Nuclear Energy, Energy Research, and the Energy Information Administration. To develop our observations about R&D, we reviewed and summarized GAO reports and testimonies on R&D since 1990.

Agency Comments and Our Evaluation

We provided a copy of our report to DOE for its review and comment. We obtained comments on the results of our work from the Department, including the Assistant Secretary, Energy Efficiency and Renewable Energy and one of his directors. DOE agreed with the funding information presented in this report and provided two general comments.

First, DOE said that the report should clearly state that both the base programs and the increases associated with the Climate Change Technology Initiative are designed to meet multiple objectives—not exclusively reducing greenhouse gas emissions. Furthermore, DOE said that the increase is for an expansion of work on the most promising technologies. We modified the text to include DOE's multiple objectives and to note that DOE's expanded funding will target the most promising technologies.

Second, DOE agreed that the five questions we raised are appropriate in the consideration of R&D funding. However, DOE said that the report attempts to provide or imply answers to each question that are uniformly negative and are based on marginally relevant examples. We do not intend our five questions as an assessment of DOE's performance in these areas. Rather, we cite previous reports to illustrate that these are areas that the Congress may want to consider when funding any R&D. Therefore, we provide examples from reports concerning DOE and other agencies. To address this comment, we modified the text to better explain the intent of our questions and the means by which DOE chooses its proposals.

As agreed with your office, unless you publicly announce its contents earlier, we plan no further distribution of this report until 14 days from the date of this letter. At that time, we will make copies of this report available to others upon request.

If you have any questions or need additional information, please contact me on (202) 512-3841. Major contributors to this report were Daren Sweeney, John Johnson, and Daniel Haas.

Sincerely yours,

Victor S. Rezendes
Director, Energy, Resources,
and Science Issues

GAO RCED

DOE's Expenditures in Support of the President's Climate Change Technology Initiative

GAO **Contents**

- Background
- Objectives
- Results in Brief
- Scope and Methodology
- Budget Information
- GAO's Observations

GAO **Background**

- President's budget requested $6.3 billion over the next 5 years (1999-2003) for Climate Change Technology Initiative (CCTI).
  - R&D and deployment of energy efficiency, renewable energy, and carbon reduction technologies ($2.7 billion).
  - Tax incentives ($3.6 billion).
  - Department of Energy (DOE) expected to implement largest portion of R&D for CCTI.

GAO **Objectives**

- Provide information on how DOE plans to alter its climate change R&D spending from 1998 to 1999.

- Provide observations regarding R&D based on previous work.

GAO **Results in Brief**

- DOE proposes over $1 billion for R&D to support CCTI for FY 1999. Approximately $729 million has been recoded as CCTI from previous year.
- Almost all CCTI dollars are to be expended through existing programs. (One new program.)
- Concept is to accelerate technology-- "more faster."

GAO

Results in Brief

- Prior to funding proposed increase, the Congress may want to consider five themes from GAO's previous work:
  - Would private sector do the research?
  - Will consumers buy the product?
  - Do benefits exceed costs?
  - Have efforts been coordinated?
  - Have implementation concerns been addressed?

GAO **Scope and Methodology**

- Reviewed DOE's budget for FY 1998 and proposed budget for FY 1999.
- Reviewed our prior work in related R&D program areas.
- Discussed R&D changes with DOE program officials.

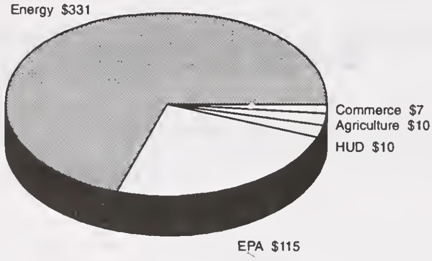
GAO RCED

Budget Information

GAO

Climate Change Technology Initiative: Governmentwide Increase (FY 1999)

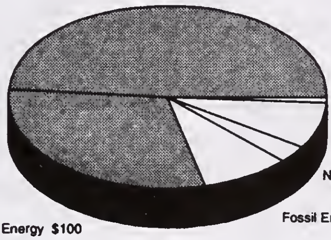
$473 million



Note. Does not include tax incentives.
Source: DOE.

GAO **Climate Change Technology Initiative: DOE Increase (FY 1999)**

$331 million



Note: Dollar amounts rounded.
Source: DOE.

GAO

DOE Climate Change R&D (FY 1998-99 funding)

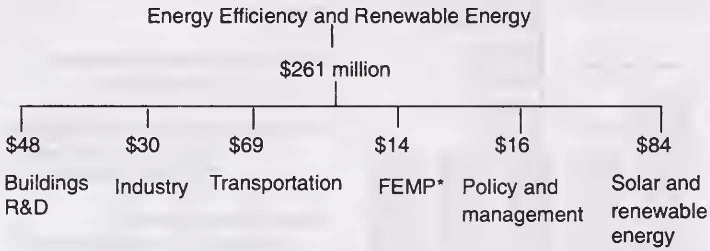
Dollars in millions

DOE organization	FY 1998 estimate*	FY 1999 request*	Change
Energy Efficiency	$456.6	$617.4	$160.8
Renewable Energy	272.2	372.3	100.1
Fossil Energy	0	30.0	30.0
Nuclear Energy	0	10.0	10.0
Energy Research	0	27.0	27.0
EIA	0	2.5	2.5

*Estimate is discretionary budget authority.
Source: DOE.

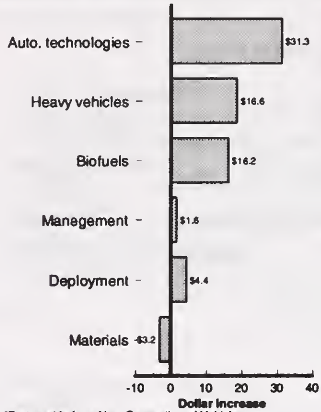
GAO

Breakout of Increase for Energy Efficiency and Renewable Energy



*FEMP = Federal Energy Management Program.

GAO **Energy Efficiency and Renewable Energy--Transportation**



Examples

Advanced Automotive Technologies
R&D for PNGV*

Advanced Heavy Vehicle Technologies
R&D for truck fuel economy
(DOT-DOE program)

Biofuels Energy Systems
Accelerate first commercial-scale demo. for ethanol from biomass waste

*Partnership for a New Generation of Vehicles.

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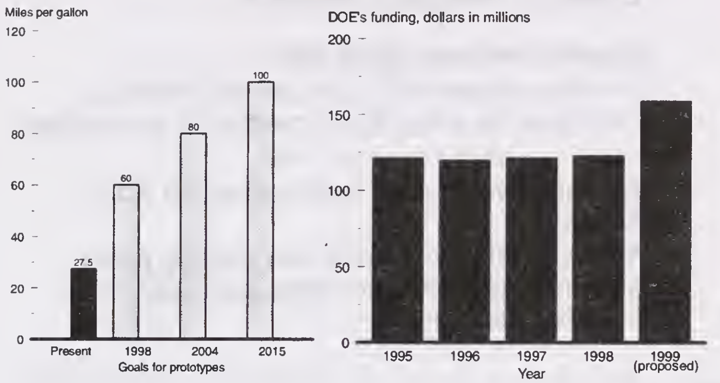
GAO

Energy Efficiency and Renewable Energy--Advanced Automotive Technologies

Partnership for a New Generation of Vehicles



GAO

Energy Efficiency and Renewable Energy--Solar and Renewable Energy

Directly Related Programs

Climate Challenge ($500,000)

Voluntary program with public-private utilities to encourage the use of pollution-reducing technologies.

U.S. Initiative on Joint Implementation ($3.4 million)

Worldwide effort to promote less polluting power systems in developing countries (as a precursor to emissions trading).

GAO Breakout of Increase for Fossil Energy

Fossil Energy

$21 million*

Coal R&D
(Advanced power systems)

- $11
  Integrated gasification/Combined cycle
- $10
  Advanced research/ Environmental technology

*Does not include $9 million OMB removed and subsequently returned.

GAO Integrated Gasification/ Combined Cycle

Refocusing Existing Programs

Vision 21 Program ($11 million)

- Producing energy through the use of high-energy components, such as fuel cells and advanced turbines. New focus will be on achieving ultra-high efficiencies by integrating component parts into a single system. Considered DOE's "showcase" power technology for its 20-year effort.

GAO

Advanced Research/Environmental Technology

Expanding Existing Programs

Carbon Sequestration Program* ($10 million)

Exploring the effects of placing sequestered CO2 in underground gas and oil wells. Greater focus on practicality, cost, and long-term effects.

*Carbon sequestration refers to the removal of carbon emissions from fossil fuels as they are burned or the capture of carbon emissions from the atmosphere and their subsequent isolation from the atmosphere.

GAO

Increase for Nuclear Energy

Nuclear Energy

$10 million

Office of Nuclear Energy, Science and Technology

GAO **Nuclear Energy**

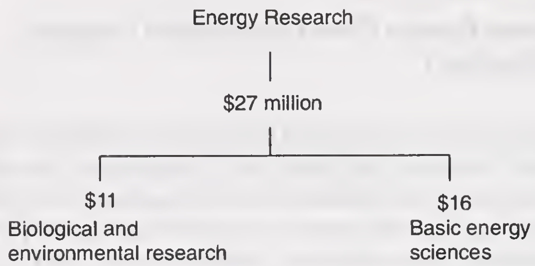
New Program

Nuclear Energy Plant Optimization Program (\$10 million)

Maintaining the operation of existing nuclear power plants. Program will focus on (1) managing the aging of nuclear power plants through development of key monitoring technologies, (2) optimizing capacity by equipping plants with new digital systems, and (3) assisting industry in meeting licensing requirements by working with NRC.

GAO

Breakout of Increase for Energy Research



GAO

Biological and Environmental Research (long-term solutions)

Health Effects and Life Sciences ($5 million)

Sequencing of Microorganisms: Understanding the total genetic makeup of methane- and hydrogen-producing organisms in an effort to explore their possible use as energy sources.

Environmental Sciences ($6 million)

Carbon Sequestration ($4 million): Research activities focused on how CO2 is sequestered in natural forest ecosystems.

Microorganism Research ($2 million): Exploring the flow of CO2 from the earth's atmosphere to the ocean and the relationship between CO2 absorption and marine microorganisms.

GAO Basic Energy Sciences (long-term solutions)

Materials Sciences ($3.5 million)
Research to support development of higher-performance materials for high-temperature combustion, novel energy-saving magnets and photovoltaic devices. Builds on existing programs but focuses on reducing CO2 production through greater efficiency.

Chemical Sciences ($4.5 million)
Research to understand molecular changes primarily during photosynthesis, catalysis, combustion, chemical separations, and energy storage.

Engineering and Geosciences ($3 million)
Focuses on terresterial sequestration of CO2 with goal of assessing the geochemistry, physics, and mechanics to determine how long CO2 would stay in place and whether it could be stored safely. To be coordinated with Fossil Energy.

Energy Biosciences ($5 million)
Previously emphasized biochemistry and biophysics of photosynthetic energy capture. Research on CO2 will focus on genetic engineering and how plants use energy to convert CO2 into products.

GAO

Increase for Energy Information Administration

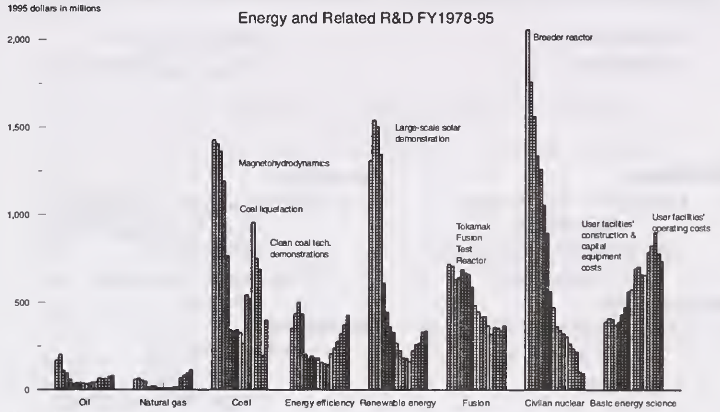
Energy Information Administration
$2.5 million

- Improve projections of energy consumption and prices for International Energy Outlook.
- Make existing energy data more useful--energy data will be converted to emissions data.

GAO RCED

R&D Context

GAO **DOE's Historic Funding for R&D**



Source: DOE.

GAO

DOE Energy R&D Subject to Opposing Arguments

Orient toward marketplace	Orient toward "basic research"

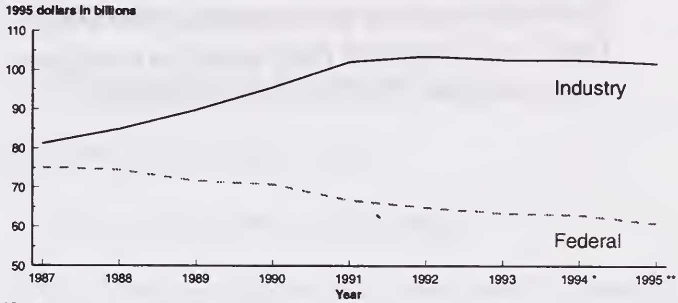
Advantages
- Near-term results/more measurable
- Enhanced competitiveness for companies

Disadvantages
- May subsidize companies to do what they would do anyway

Advantages
- Provide scientific knowledge to support development of new products
- Resource for successful innovation

Disadvantages
- Difficult to measure results/riskier, longer-term investment

GAO **Investment in Federal and Private Energy R&D**



* Preliminary
** Estimate
Source: National Science Foundation.

GAO

It Is Difficult to Measure Outcomes and Performance of Many Types of R&D

As a result, we are providing several themes from our previous work in R&D that the Congress may want to consider as it reviews DOE's R&D proposal.

GAO

Themes From GAO Reports

1. Would private sector do the research?
2. Will consumers buy the product?
3. Do benefits exceed costs?
4. Have efforts been coordinated?
5. Have implementation concerns been addressed?

GAO **Displacement of Private Research**

Would private industry perform the R&D without government funding?

- Advanced Technology Program
- Clean Coal Technology Program
- Identifying market failures
- Electricity R&D

GAO Displacement of Private Research

Advanced Technology Program (RCED-96-47)
(RCED/OCE-98-83R)

ATP funded research that would have been funded by the private sector. 40% of "winners" said they would have continued without funding. Some of the "near winners" financed their projects using private funds only.

National Institute of Science and Technology (NIST) now considers "market failures" when selecting projects. However, it is still difficult to identify where market failures occur.

GAO

Displacement of Private Research

Fossil Fuels: Improvements Needed in DOE's Clean Coal Technology Program (RCED-92-17)

In the Clean Coal Technology Program, DOE funded projects that would demonstrate technologies already in commercial use overseas.

These projects may not have been the best use of federal resources because the technologies might have been commercialized without federal assistance.

DOE does not assess whether technologies are likely to be commercialized without federal assistance before selecting projects.

GAO **Displacement of Private Research**

Federal Budget: Choosing Public Investment Programs (AIMD-93-25)

Public investments like R&D can arise where market failures occur. Market failures include (1) undersupply of public goods, (2) externalities, and (3) excessive risk. Excessive risk is often a problem in large-scale R&D projects.

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GAO

Displacement of Private Research

Federal Research: Changes in Electricity-Related R&D Funding (RCED-96-203)

Utilities are cutting R&D budgets in anticipation of greater industry competition. Shift is away from longer-term projects that may benefit many utilities. Shift is toward proprietary R&D with a short-term payback.

GAO **Marketplace Competitiveness**

Can the technology that DOE develops compete in the marketplace?

- Advanced batteries
- Energy efficiency research
- Alternative fuels
- Clean coal technology

GAO **Marketplace Competitiveness**

Electric Vehicles: Efforts to Complete Advanced Battery Development Will Require More Time and Funding (RCED-95-234)

Advanced Battery Consortium has not proven that batteries meeting long-term technological goals are feasible. Batteries meeting midterm goals may be achievable, but electric vehicles with them not competitive in performance or cost. Carmakers said large subsidies will be needed.

GAO

Marketplace Competitiveness

Full Disclosure of National Energy Strategy Analyses Needed to Enhance Strategy's Credibility (T-RCED-91-76)

DOE's energy efficiency research may be less effective while energy prices are low. Low prices discourage the use of energy-efficient technology. Higher energy prices would encourage research, but administration did not pursue policies to raise prices.

GAO **Marketplace Competitiveness**

Alternative Fuels: Experiences of Brazil, Canada, and New Zealand in Using Alternative Motor Fuels (RCED-92-119)

Governments became the catalyst for action to encourage industry to promote use of alternative fuels through lower taxes and price subsidies. Providing lower prices through subsidies was most important reason why consumers bought alternative fuels.

Sustained government commitment important because switch to alternative fuels requires long-term financial, technological, and regulatory changes.

GAO **Marketplace Competitiveness**

Alternative Fuels: Experiences of Countries Using Alternative Motor Fuels (T-RCED-91-85)

Consumers' acceptance of alternative fuels requires a price advantage over gasoline-fueled vehicles. Government should be catalyst to encourage consumers' use of and industry involvement in alternative fuels.

GAO Marketplace Competitiveness

Fossil Fuels: Outlook for Utilities' Potential Use of Clean Coal Technologies (RCED-90-165).

Without acid rain mandates, utility industry willing to use clean coal technologies at only 5 percent of coal-fired units. With mandates, industry would consider using technologies at up to 50 percent of units to reduce SO_2 and up to 75 percent of units to reduce NO_x.

Technologies may not contribute to acid rain reduction in next 15 years due to uncertainty about when they will be available.

GAO

Cost and Benefits/Performance Measures

Has DOE thoroughly analyzed the costs and benefits of its R&D proposals, and what specific performance measures will it use?

- DOE's Success Stories report
- Clean Coal Technology Program
- SEMATECH
- EPA's voluntary climate change programs

GAO

Cost and Benefits/Performance Measures

DOE's Success Stories report (RCED-96-120R)

DOE made some valid claims about the benefits of its applied research. Some of these benefits may be substantial, but we found problems with the analyses DOE used to support benefits in most cases.

DOE did not report how much it spent on R&D for many of the technologies.

GAO

Cost and Benefits/Performance Measures

Fossil Fuels: Improvements Needed in DOE's Clean Coal Technology Program (RCED-92-17)

DOE's selection of some projects, while meeting selection criteria, may not have been the most cost-effective use of federal funds.

Some projects may not have widespread use because they are not expected to reduce emissions as much as existing technology or because they serve a limited market.

GAO **Cost and Benefits/Performance Measures**

Federal Research: SEMATECH's Technological Progress and Proposed R&D Program

(RCED-92-223BR)

SEMATECH appeared to be reaching its technological goal to produce state-of-the-art semiconductors using only U.S. equipment. Domestic semiconductor manufacturers arrested a decline in world market share. However, it was unclear how much of this was attributable to SEMATECH.

GAO

Cost and Benefits/Performance Measures

Global Warming: Information on the Results of Four of EPA's Voluntary Climate Change Programs (RCED-97-163)

In assessing the benefits from two of four climate change action plan programs, EPA adjusted reductions in greenhouse gas emissions to account only for the effects of its efforts. In two other programs, it did not adjust reported reductions.

GAO **Coordination and Consistency**

Has DOE assessed whether the proposed research is consistent with its mission statement, strategic plan, and ongoing R&D efforts? Has it coordinated with the R&D efforts of other agencies?

GAO **Administration/Implementation**

Does DOE have the administrative structure in place to effectively implement its R&D programs?

- NIST's Advanced Technology Program (ATP)
- Clean Coal Technology Program
    - cost reviews
    - cost-sharing guidelines

GAO **Administration/Implementation**

NIST's Unobligated Funds (RCED-95-166R)

In FY95, NIST's ATP funding more than doubled from FY94. NIST planned to make about twice as many awards as it did the previous year.

NIST did not increase administrative staff at the same rate as its planned awards.

NIST did not make all awards and carried over $136.4 million at the end of FY95.

GAO **Administration/Implementation**

Fossil Fuels: Ways to Strengthen Controls Over Clean Coal Technology Project Costs (RCED-93-104)

DOE made a good effort to review the reasonableness of sponsors' proposed project costs before projects began. However, after projects started, DOE did not audit costs in a timely manner.

GAO Administration/Implementation

Fossil Fuels: Lessons Learned in DOE's Clean Coal Technology Program (RCED-94-174)

Program shows that government and private sector can work together to develop new technologies.

Lessons learned include (1) obtaining advance funding, (2) using cooperative agreements, (3) establishing federal cost-sharing limits, (4) obtaining early participation of industry, and (5) establishing a comprehensive process to evaluate and select projects.

United States General Accounting Office

GAO

Report to the Ranking Minority Member, Committee on Commerce, House of Representatives

June 1998

CLIMATE CHANGE

Information on the U.S. Initiative on Joint Implementation

GAO/RCED-98-154

GAO

United States
General Accounting Office
Washington, D.C. 20548

Resources, Community, and
Economic Development Division

B-279654

June 29, 1998

The Honorable John D. Dingell
Ranking Minority Member
Committee on Commerce
House of Representatives

Dear Mr. Dingell:

Increasing emissions of carbon dioxide, methane, and other heat-trapping greenhouse gases generated by human activity are believed to contribute to global climate change. Accordingly, the United States, France, Japan, and 35 other industrialized nations negotiated an agreement—in Kyoto, Japan, in December 1997—that would limit their overall greenhouse gas emissions by 2012.[1] Although the details have not yet been worked out, the nations that are parties to this agreement may be allowed to work with other nations to achieve emissions reductions in a cost-effective manner. A concept being considered would allow a developed country to meet at least part of its obligation to reduce greenhouse gas emissions by receiving credit for investing in a project that reduces emissions in another country.

To evaluate different approaches to implementing this concept, in 1994 the United States established a pilot program, known as the U.S. Initiative on Joint Implementation. This program encourages investments by U.S. entities (largely private sector firms) in projects to reduce greenhouse gas emissions outside the United States. Under the Initiative, U.S. entities, in cooperation with non-U.S. partners, develop project proposals and submit them to the Initiative for review and evaluation to determine which projects will be accepted into the program. The decision about whether to accept a particular project into the program is made by the Initiative's Evaluation Panel, comprising senior policy-level executives of eight federal agencies.[2] In recent years, several other countries have also established pilot programs similar to the U.S. Initiative.

Because of your concern about the costs of reducing U.S. greenhouse gas emissions, you asked us to examine selected aspects of the U.S. pilot

[1]This agreement, reached at the Third Conference of the Parties to the United Nations Framework Convention on Climate Change after more than 2 years of international negotiations, is known as the Kyoto Protocol. The Protocol is open for signature from March 16, 1998, until March 15, 1999. The Protocol must be signed by the President and ratified by the Senate before its provisions are binding for the United States. As of June 1998, the President had not signed the Protocol.

[2]Specifically, these agencies are the departments of Agriculture, Commerce, Energy, State, the Interior, and the Treasury, as well as the Agency for International Development and the Environmental Protection Agency.

program on joint implementation. Specifically, you asked that we provide information on (1) the criteria used to accept proposed projects, (2) the number and types of projects accepted, (3) the status of the seven projects accepted in the first round of proposals in February 1995, and (4) the estimated benefits of pilot projects in terms of emissions reductions.

Results in Brief

The Initiative's Evaluation Panel uses nine criteria to evaluate proposed projects for acceptance into the program. Among the criteria are acceptance by the host country, a reduction in greenhouse gases that would result from the proposed project and that would not have occurred otherwise, and a mechanism to verify the project's results. The U.S. program generally has more criteria than similar programs administered by certain other countries. Also, the U.S. criteria are stricter in some respects, for example, by requiring that benefits be maintained over time.

Through March 1998, Initiative officials had reviewed proposals for 97 different projects and accepted 32 of them. Of the 32 accepted projects, 17 involve reducing greenhouse gas emissions, for example, by constructing and operating a hydroelectric plant that will provide electricity previously produced by burning fossil fuels. The other 15 involve capturing greenhouse gases already emitted, for example, by planting forests or maintaining forests that would have otherwise been harvested.[3] Also, 31 of the 32 projects are intended to reduce emissions of or capture carbon dioxide; the other project is intended to reduce methane emissions.

Of the seven projects accepted into the Initiative as a result of the first round of evaluations in February 1995, five are in the process of being implemented. This means that land has been acquired or facilities have been built, and the projects are in the process of reducing or capturing greenhouse gas emissions. For example, in one case, a facility built in the Czech Republic to generate electricity by burning natural gas rather than coal began operations in September 1996. According to Initiative officials, as of March 1998, the remaining two projects—one that would reduce greenhouse gas emissions and one that would capture these emissions from the atmosphere—had not progressed because their developers had not been able to obtain financing.

The projects' developers estimate that, over a period of up to 60 years, the 32 approved projects, if fully funded and implemented, will result in net

[3]When forests are cleared for agriculture or development, most of the carbon in the burned or decomposing trees escapes to the atmosphere. However, when new forests are planted, the growing trees capture carbon dioxide (for use in photosynthesis), removing it from the atmosphere.

emissions reductions of about 200 million metric tons of carbon dioxide and 1.3 million metric tons of methane. Initiative staff do not verify or attest to the reliability of the "net greenhouse gas benefits" estimated by the projects' developers. In part, this is because standard methods for estimating projects' emissions reduction benefits specific to the U.S. Initiative have not been developed. The Environmental Protection Agency (EPA) has funded studies to develop standard methods for calculating projects' benefits. According to EPA officials, these studies should be completed by the end of fiscal year 1998.

Background

Many billions of tons of carbon in the form of carbon dioxide, a major greenhouse gas, are exchanged naturally each year between the atmosphere, the oceans, and vegetation on the land. Greenhouse gas levels in the atmosphere are determined by the difference between processes that generate greenhouse gases (sources) and processes that destroy or remove them (sinks). Oceans and forests are the primary natural sinks. Humans have affected greenhouse gas levels (primarily carbon dioxide) by introducing new sources—primarily by burning fossil fuels such as coal, oil, and natural gas—and by interfering with natural sinks—primarily by deforestation. Scientists have estimated, for example, that as a result of human activity, the level of carbon dioxide emissions in the atmosphere has risen by almost 30 percent since industrialization began about 250 years ago.[4] Among the nations of the world, the United States contributes the largest amount of carbon dioxide emissions from human activity.

In a July 1997 report to the United Nations Framework Convention on Climate Change, the United States estimated that its carbon dioxide emissions from human activity in 1995 were about 5.2 billion metric tons. The United States also estimated that U.S. emissions of methane, another major greenhouse gas, from human activity were about 31 million metric tons (which is equivalent to about 650 million metric tons of carbon dioxide in global warming potential over a 100-year period).[5] The emissions of these two greenhouse gases represent more than 95 percent of the total U.S. greenhouse gas emissions reported. The report also stated

[4]Climate Change 1995, The Science of Climate Change, from a summary approved by Working Group I in November 1995 for the Second Assessment Report of the Intergovernmental Panel of Climate Change.

[5]Greenhouse gases have varied effects on the atmosphere as measured by their global warming potentials over a specified period of time. These global warming potentials are applied to emissions to arrive at a common measure for the greenhouse gases; the measure can be expressed in either million metric tons of carbon dioxide or carbon equivalent. Carbon dioxide units can be converted into carbon units by dividing by 3.67.

that the 1995 emissions levels for carbon dioxide had increased approximately 6 percent and for methane, approximately 4 percent above 1990 levels.

Recognizing the potential for cost-effective greenhouse gas emissions reductions in other countries, the United States developed ground rules for a joint implementation program, formally known as the U.S. Initiative on Joint Implementation.[6] Published in final form in June 1994, these ground rules established a pilot program, which is intended to evaluate possible approaches to joint implementation, including developing methods to measure and verify the projects' achievements and helping to serve as a model for international consideration of joint implementation.[7] Although participants in the pilot program do not receive formal credit for the emissions reductions achieved as a result of the pilot projects, they may receive public recognition for their efforts to combat climate change. Other motivating factors for some participants, according to Initiative officials and other studies of the joint implementation concept, include establishing operations or markets for their products in the host countries and anticipation that their pilot projects will be eligible for credit after the year 2000, when the United Nations' pilot ends.[8]

An interagency Initiative Evaluation Panel, cochaired by senior executives of the Department of Energy (DOE) and EPA, accepts projects into the program and is authorized to certify their net emissions reductions. The Evaluation Panel is supported by an interagency Secretariat, which manages the program's day-to-day operations, including the implementation of the application and review procedures for project proposals. In 1997, the Secretariat was staffed by eight employees on detail from DOE and EPA. Five of these employees spent less than full-time on the Initiative's activities. In addition to these employees, however, the Secretariat relies on the expertise and contributions from staff in the other

[6]This program is frequently referred to by its acronym USIJI. For increased readability, we use the term "Initiative."

[7]In 1995, the United States and other countries that signed the United Nations Framework Convention on Climate Change also established a pilot program within the United Nations called Activities Implemented Jointly. Under this program, participating countries may report to the United Nations on joint implementation projects that they have sponsored. The pilot program is to be evaluated no later than the end of 1999.

[8]These studies include Assessing the Constraints and Opportunities for Private-Sector Participation in Activities Implemented Jointly: Two Case Studies From the U.S. Initiative for Joint Implementation, September 1997, by M. Powell, R. Lile, and M. Toman, Resources for the Future, and Joint Implementation and Its Alternatives: Choosing Systems to Distribute Global Emissions Abatement and Finance, April 1997, by E. Parson and K. Fisher-Vanden, Center for Science and International Affairs, John F. Kennedy School of Government, Harvard University.

federal agencies that support the Initiative. The Initiative's budget was $3.8 million in fiscal year 1996 and $2.6 million in fiscal year 1997.

Under the Kyoto Protocol, negotiated in December 1997, the United States would be required to reduce its emissions of six greenhouse gases—namely, carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulphur hexafluoride—7 percent below its 1990 emissions level by 2012. The Kyoto Protocol also includes provisions for market-based approaches to reduce emissions of greenhouse gases. Such approaches include emissions trading, joint implementation, and the "clean development mechanism."[9] The philosophy behind these approaches is that the cost of reducing or capturing emissions varies among countries and that it is more efficient to seek the reductions where the cost is the least.

Nine Criteria Are Used to Judge Project Proposals

Through the first six rounds of submissions, Initiative officials have used nine criteria and considered four other factors to determine which proposals to accept. The criteria primarily involve ways of measuring the project's effect in reducing emissions and steps for verifying these reductions. One of the criteria also requires the project's participants to provide annual reports to the Evaluation Panel on the emissions reduced or captured (sequestered) by the project. The other four factors considered involve determining whether the actions of U.S. participants and the host country support the objectives of United Nations Framework Convention on Climate Change and the potential positive and negative effects of the project on greenhouse gas emissions outside the project's boundaries and apart from its effect on greenhouse gas emissions. The Initiative uses more criteria than do certain other countries with similar programs, and the U.S. criteria are more strict in some respects.

When the pilot program was being developed, an interagency task force led by the State Department established criteria for determining which proposed projects would be accepted into the program. The criteria were developed to help ensure that proposed projects meet the development goals of the host country, while providing greenhouse gas benefits beyond those that would have occurred in the absence of the project. Moreover,

[9] Prior to the Kyoto Protocol, joint implementation was the terminology generally used for the concept that would allow a developed country to meet at least part of its obligation for reducing greenhouse gas emissions by receiving credit for investing in projects that reduce emissions in another country. The Kyoto Protocol, however, makes a distinction on the basis of whether the investment is in a developing or developed country: Investments in developing countries are included under the Protocol's clean development mechanism provisions and investments in other developed countries are included under its joint implementation provisions.

the criteria are intended to help ensure that the projects result in real, measurable net emissions reductions.

An initial set of nine criteria was proposed in a Federal Register notice on December 17, 1993. Twelve organizations and individuals submitted comments on the proposed criteria. On the basis of these comments, the criteria were revised, and the final criteria were published in the Federal Register on June 1, 1994. These criteria now have been used for evaluating the six rounds of proposals considered through March 1998.

Most of the nine criteria relate to identifying and measuring a project's benefits. For example, one criterion asks whether the proposal provides enough information to determine the level of current and future emissions both with and without the project. A second asks whether the proposal contains adequate provisions for tracking the emissions reduced or sequestered. A third asks whether the proposal provides adequate assurance that the benefits will not be lost or reversed over time. Other criteria relate to such matters as acceptance by the host country and annual reporting, including the greenhouse gas benefits as they are attained. Among the other four factors considered, one is whether the project has potential positive or negative effects on the host country's employment and public health. (All nine criteria and four other considerations used in the project evaluation process are paraphrased in app. I.)

The U.S. Initiative generally uses more criteria than did certain other countries with similar programs, and the criteria are stricter, in some respects, than the criteria used in other countries' programs, according to our analysis of a 1996 report prepared for the Agency for International Development.[10] This report described the criteria of the U.S. Initiative and similar programs in Australia, Canada, Germany, Japan, and the Netherlands. Our analysis of this information showed that the number of criteria used by the U.S. Initiative (nine) was equal to the number used by the Netherlands and larger than the number used by the other four countries (four to seven each). In addition, the U.S. criteria were stricter in some respects. For example, only the U.S. Initiative had requirements for maintaining benefits over time and for external verification of benefits. Conversely, two other countries—Germany and the Netherlands—had a criterion related to stimulating the use of modern technology or renewable energy.

[10] Implementing JI/AIJ: A Guide for Establishing Joint Implementation Programs, Center for Sustainable Development in the Americas (Nov 1996).

In a July 1996 report to the Secretariat of the United Nations Framework Convention on Climate Change, the Initiative said that its Evaluation Panel, which is responsible for accepting or rejecting project proposals for inclusion in its program, considers not only how a project measures against all criteria, but also how the project contributes to the pilot program. The report stated that while failure on any single criterion could keep a project from being approved, the panel may find relatively poor performance on one criterion to be outweighed by excellent performance on another. The report further stated that because the criteria were also being tested for their appropriateness, the Evaluation Panel did not use a single rigid approach to applying the criteria but remained flexible in their interpretation and application to each project.

In our review of Initiative files, we found that 18 of the 32 projects accepted during the first six rounds had been accepted even though internal documentation indicated that the proposals were judged as not clearly meeting one or more of the nine criteria. For example, reviewers raised questions about a project involving the development and operation of a wind electricity-generating plant. The project review documentation noted that because the project had been under discussion since 1992, a year before the U.S. pilot program was announced, it was not clear that the project was initiated either in response to or in reasonable anticipation of the pilot program—one of the nine criteria for a project's acceptance. The documentation also indicated that the project's developers believed that acceptance of the project into the Initiative would better enable them to obtain the necessary funding for the project. The Evaluation Panel accepted this project. An Initiative official said that individual technical reviewers sometimes interpreted the criteria differently and came to different conclusions. In such cases, the Initiative's Secretariat labels these findings as "less than clear compliance" and requests that the Evaluation Panel make this judgment on a case-by-case basis. According to the Secretariat, when the Evaluation Panel accepts such projects, it believes that the criteria were adequately met.[11]

About One-Third of the Proposed Projects Have Been Accepted

Of the 97 proposed projects submitted during six evaluation rounds, 32 projects have been accepted into the program. Of the accepted projects, 17 are designed to reduce emissions, and 15 are designed to sequester emissions. All but one of the projects are aimed at reducing or

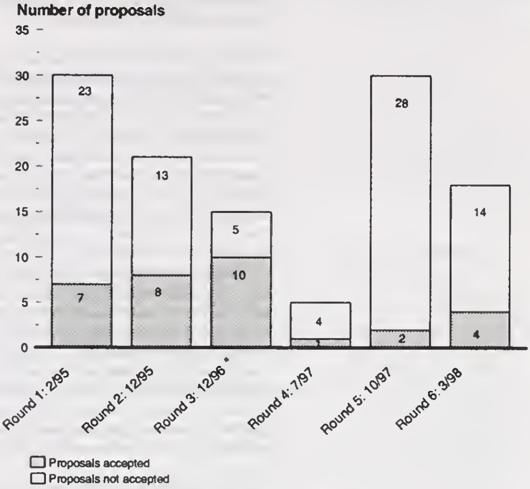
[11]According to an Initiative official, the criteria that have been the most difficult to interpret consistently are those related to "additionality," which is discussed later in this report.

sequestering carbon dioxide emissions, while the other project is aimed at reducing methane emissions.

Through the six rounds, a total of 119 proposals have been submitted, 22 of which have been submitted twice. Thus, 97 separate proposals have been submitted. Thirty applications were submitted in the first round. Thereafter, the number of applications declined steadily to five applications in the fourth round. Although the number of applications rebounded to 30 in round five, it declined again to 18 in the most recent round. Secretariat staff suggested some possible explanations for the variations in the number of project proposals submitted in the various rounds. The staff suggested that the two largest rounds (rounds one and five), which occurred immediately prior to the First and Third Conferences of the Parties to the United Nations Framework Convention on Climate Change, were the result of project developers' expectations that international crediting of joint implementation projects might be negotiated at those sessions. The staff also suggested that the smallest number of proposals came in round four because it was the first round occurring after the Initiative increased the number of rounds conducted a year from one to three and the resulting short period of time between rounds three and four (about 4 months). According to the Secretariat's Director, in response to project developers' expressed desires for a quicker turnaround process, the Initiative increased the frequency of its evaluation rounds by streamlining its application procedures.

A total of 32 proposals have been accepted into the Initiative, including at least one proposal in each round. The proportion of proposals accepted increased from 23 percent in round one to 67 percent in round three. However, this proportion declined to 20 percent in round four and 7 percent in round five. Secretariat officials said that they had not attempted to determine a reason for this decline, but they pointed out that many of the proposals submitted for round five were found not to be complete. Our analysis showed that the project reviewers found 19 of the 30 round-five proposals, or more than 60 percent, did not contain sufficient information to permit a complete evaluation. The proportion accepted in round six was about 22 percent. (See fig. 1.)

Figure 1: Proposed and Accepted Projects, by Round



[a]Round three (12/96) includes three projects accepted in 2/97 and 3/97.

Of the 32 approved projects, 31 focus on carbon dioxide, while the other project focuses on methane. Seventeen of the approved projects are designed to reduce emissions. For example, a project in Costa Rica involves the construction and operation of a privately owned and operated hydroelectric plant. The electricity generated by this plant will displace electricity that would have otherwise been generated by burning fossil fuels, thus reducing carbon dioxide emissions. The project that focuses on reducing methane emissions is located in the Russian Federation and will capture natural gas that is now escaping from a transmission and distribution system by sealing valves at two compressor stations.

The other 15 approved projects are designed to capture carbon dioxide that is already in the atmosphere. For example, one project will preserve a tropical forest in Costa Rica by purchasing over 6,000 acres of privately owned land. Because, according to the project proposal, this forest land likely would have been either harvested or converted for agricultural use within the next 15 years, the greenhouse gas benefits for this project will accrue from preserving the existing trees.

The 32 approved projects are located in 12 countries. Of these, the largest number, 16 (50 percent), are located in Central America. Another seven projects (22 percent) are located in Central and Eastern Europe, including the Russian Federation. The other nine projects (28 percent) are located in North America, specifically, Mexico (four projects); South America (three projects); and Asia (two projects).

Table 1: Location and Type of Approved Projects

Location	Total projects	Reduce emissions	Sequester emissions
Central America	16	9	7
Central and Eastern Europe	7	5	2
North America	4	1	3
South America	3	1	2
Asia	2	1	1
Total	**32**	**17**	**15**

A wide range of U.S. organizations are participating in the Initiative. These include private industry, environmental nongovernmental organizations, universities, and federal agencies. Private industry includes electric utility, oil, and other companies that have developed techniques to reduce greenhouse gas emissions. The nongovernmental organizations include the Center for Clean Air Policy, the National Fish and Wildlife Foundation, and The Nature Conservancy. The nongovernmental organizations provide funding in some cases, but more often they act as project facilitators.

Of the First Seven Projects Approved, Five Are in the Process of Being Implemented

Of the seven projects approved in the first round in February 1995, five have been or are being implemented, and two have not yet started. Each of these projects has at least one U.S. participant; one project has seven.

Five of the seven projects approved in the first round are reducing or sequestering emissions, according to information collected by the

Initiative's staff in March 1998. Of these five, two projects are intended to reduce emissions. In both of these cases, the facilities have been built and are now in operation. For example, a project in the Czech Republic involving several energy efficiency improvements at a district heating facility, including the conversion of a coal-burning plant to natural gas, was completed and became operational in September 1996. The other three projects are intended to sequester emissions. For these projects, one or more of the following processes have been completed: Land has been purchased; surveys have been completed; and trees have been planted. For example, at one sequestration project in Costa Rica, land included in the project proposal and identified as being in danger of deforestation has been purchased and conveyed to Costa Rica's national park service.

The remaining two projects have not been implemented because of an inability to obtain financing, according to information provided to Initiative staff by these projects' representatives in March 1998. These two projects include one intended to sequester emissions and one intended to reduce emissions. For one of these projects, a sequestration project located in Costa Rica, the host-country partners reported that they had not been successful in obtaining financing for either this project or another sequestration project approved in the Initiative's second evaluation round. However, the partners said that the affected forest area covered by these two projects would be absorbed into two other joint implementation projects, one a U.S. Initiative project accepted in the fourth evaluation round in July 1997 and the other a Norwegian pilot joint implementation project. The partners further said that for this reason they planned to report that the two projects for which they have not obtained financing should not continue to be listed as separate projects. According to Initiative staff, the developer of the other project that has not progressed is continuing efforts to obtain financing. This project is located in Honduras and is intended to reduce carbon dioxide emissions by providing for solar-based electrification in rural areas. The status as of March 1998 for each project accepted during the first evaluation round is shown in table 2.

Table 2: Status of the Seven Projects Accepted in February 1995

Project	Country	Objective	Status, as of March 1998
Projects to reduce emissions			
City of Decin fuel switching for district heating	Czech Republic	Reduce emissions by switching from coal to natural gas	Facility became operational in September 1996.
Plantas Eolicas S.A. wind facility	Costa Rica	Reduce emissions by substituting wind power for fossil fuel combustion	Facility became operational in June 1996.
Solar-based rural electrification	Honduras	Reduce emissions by using photovoltaic-powered electric lights in rural areas, instead of kerosene lamps	Developer has not been successful in obtaining financing.
Projects to sequester gases			
Ecoland: Piedras Blancas National Park	Costa Rica	Sequester carbon by preventing deforestation	Land purchases completed.
Rusafor: Saratov afforestation project	Russian Federation	Sequester carbon by planting trees on marginal agricultural land and in burned pine forest	All sites have been cleared and reforested
Carfix: Sustainable forest management	Costa Rica	Sequester carbon by reforestation, sustainable management of natural forest, and forest regeneration	Project has not been successful in obtaining financing. Developers plan to absorb a portion of this project into two recently accepted pilot projects.
Rio Bravo Carbon Sequestration Pilot Project	Belize	Sequester carbon by preventing deforestation and implementing a sustainable forest management program	Experiments on mahogany regeneration and reduced-impact logging conducted. A fire control regimen implemented.

The seven projects accepted during the first round of evaluations had between one and seven U.S. participants. For example, the sustainable forest management project in Costa Rica had one U.S. participant, Wachovia Timberland Investment Management; the U.S. Initiative project that will absorb much of this project also has a single U.S. partner, Earth Council Foundation—U.S. Conversely, the Rio Bravo Carbon Sequestration Pilot Project in Belize has seven U.S. participants, including The Nature Conservancy, Wisconsin Electric Power Company, and Detroit Edison Corporation.

Methodologies for Verifying Project Benefits Are Being Developed

Standard methodologies that can be used either to estimate a project's greenhouse gas benefits or to certify a project's net emissions benefits are being developed. Based on information provided by the projects' developers, the total estimated greenhouse gas benefits for the 32 projects accepted into the Initiative as of March 1998 is equivalent to about 235 million metric tons of carbon dioxide over a period of up to 60 years. Although the Initiative reviews the methods, data, and assumptions project developers use to estimate net greenhouse gas benefits, it does not attest to the validity of those estimates. The Initiative does have responsibility, however, for monitoring and verifying emissions reductions as they are attained. As of the latest reporting date (July 1997), only one of the 25 projects accepted into the Initiative had reported emissions reduction benefits. According to the Initiative staff, it has not yet verified these reported emissions reductions partially because no standard methods for determining greenhouse gas benefits specific to joint implementation projects have been developed. EPA, as part of its role in providing support to the Secretariat, is funding studies of several issues related to determining emissions benefits. One objective of EPA-funded research is to develop standard methodologies.

The 32 projects accepted into the Initiative are projected to yield benefits over time periods as short as 3 years (for one wind power generation project and one forest preservation project) and as long as 60 years (for two reforestation projects). Based on the project developers' estimates, these 32 projects will reduce greenhouse gases by more than 200 million metric tons of carbon dioxide and 1.3 million metric tons of methane (1.3 million metric tons of methane is equivalent, in terms of global warming potential, to about 31 million metric tons of carbon dioxide). Of the total net greenhouse gas benefits, equivalent to approximately 235 million metric tons of carbon dioxide, about 65 million tons, or 28 percent, is attributed to emissions reduction projects, while the remaining 170 million tons, or 72 percent, is attributed to sequestration projects. For example, one project in Nicaragua involves constructing and operating a flash-steam power generation facility, using the country's abundant geothermal resources, that will emit only small amounts of carbon dioxide. According to the latest project report, this facility will displace an equivalent-size facility using fossil fuels and is expected to reduce carbon dioxide emissions by about 14 million metric tons over about 38 years. Similarly, a sequestration project in Ecuador that involves purchasing about 5,000 acres of tropical forest will be incorporated into a newly created reserve. According to the project's developers, by preventing the conversion of these lands, expected to occur over the next 3 years, to marginal cropland and cattle pasture, the project will result in net greenhouse gas benefits of more than 1 million tons of carbon dioxide. Although the Initiative reviews, as part of the proposal review process, the methods, data, and assumptions that the project developers used to develop their estimates, it does not attest to their validity.

As of the last reporting period (July 1997), only one accepted project—a project that combines land acquisition and a sustainable forestry program to achieve emissions reductions through forest growth—had reported greenhouse gas benefits. The emissions reductions reported for this project were 807,468 metric tons of carbon dioxide a year for calendar years 1995 and 1996. The project developers for another four implemented projects reported to the Initiative staff in March 1998 that their projects were in operation and achieving greenhouse gas benefits but pointed out that the benefit data they provided at that time were estimates because either detailed monitoring results were not available or the monitoring results had not been verified. According to the Initiative's deputy director, these reductions are likely to be reported in the 1998 annual report.

Although the Initiative's ground rules state that the Evaluation Panel is responsible for certifying the greenhouse gas benefits estimated for the projects, the Initiative staff said that it does not currently verify reported emissions reductions. The staff acknowledged that it has neither provided standard monitoring guidance to projects nor reviewed the monitoring plans for most projects, but recognizes that its efforts in these areas need to be strengthened. The staff attributed its limited progress in these areas to the small number of projects that are now either funded or implemented and the absence of standard methods for determining greenhouse gas benefits specific to joint implementation projects. The staff also said that it was waiting on the EPA-sponsored research that will provide guidelines for the development of monitoring plans and verification methods to be completed before certifying reported emissions reductions.

EPA is funding research to develop standard methods for quantifying emissions benefits. Recently completed studies focused on implementing uniform reporting formats for the pilot projects (compatible with a reporting form used by the United Nations Framework Convention on Climate Change for its pilot program) and refining ways to measure greenhouse gas emissions from projects. Currently under way is a study to examine various aspects of project baselines (to estimate what would have happened if the pilot project had not been implemented) and emissions additionality (to help ensure that project benefits are in addition to what would otherwise have happened). In the context of the pilot program, additionality refers to project acceptance criteria that are designed to ensure that the financing of a proposed project would not have occurred otherwise, called financial additionality, and that the associated reduction in emissions would likewise not have occurred, called emissions additionality.

Some phases of the research have been completed and are undergoing review, while other phases are continuing. According to EPA officials, standard methods for estimating emissions reduction benefits would help to move the program from its current pilot phase to a fully implemented program with credible reductions. The officials were not able to say how long the development of the standard methods might take, but current studies being funded by EPA are to be completed during this fiscal year. An EPA official also said that the agency is currently funding research on methodologies for monitoring and plans to fund research on methodologies for verification in the future. (App. II provides additional information about efforts to develop standard methods.)

Agency Comments

We provided a draft of this report to the Director of the Joint Implementation Secretariat and the Administrator of EPA for review and comment. The Secretariat's Director said that the report is generally a balanced assessment of the Initiative, with a useful analysis of the projects and the consideration of those projects by the Initiative's Secretariat and Evaluation Panel. (The Secretariat's comments and our responses appear in app. III.) The Director also suggested technical corrections to the draft report, which were incorporated as appropriate. EPA's Office of Economy and Environment, within its Office of Policy, Planning and Evaluation, also suggested technical corrections, which were incorporated as appropriate.

To accomplish our objectives, we interviewed officials of the Initiative's Secretariat, EPA, and the Department of State. At the Secretariat offices, we obtained and reviewed information pertaining to the Initiative's project evaluation process, including policy memorandums, technical review summaries of project proposals, and decision memorandums prepared to assist the Evaluation Panel with its decision-making process. At EPA, we obtained and reviewed information related to its efforts to develop standard methods for measuring greenhouse gas emissions and for estimating projects' emissions reduction benefits. At the Department of State, we obtained information on the development of the ground rules for the U.S. pilot program and public comments on notices published in the Federal Register. We limited our work on the third objective (relating to the status of approved projects) to those approved in the first round because they had had the longest period of time to be developed. This information was obtained by reviewing the latest annual reports prepared by the participants in the accepted projects. The Secretariat staff assisted us in obtaining information from the project participants when information contained in the reports was not clear. We did not independently verify the information provided by the Secretariat.

We also reviewed available documents about the joint implementation concept, the U.S. Initiative, and the United Nations' pilot program. We conducted our review from September 1997 through June 1998 in accordance with generally accepted government auditing standards.

As arranged with your office, unless you publicly announce the report's contents earlier, we plan no further distribution of this report for 15 days. At that time, we will send copies to the appropriate congressional committees, the Director of the Secretariat, and the Administrator of EPA. We will also make copies available to others upon request.

Major contributors to this report were David Marwick; Stacy L. Morgan; William H. Roach, Jr.; and Robert D. Wurster. If you have any questions or need additional information, please call me at (202) 512-6111.

Sincerely yours,

Peter F. Guerrero
Director, Environmental
Protection Issues

Contents

Abbreviations

DOE	Department of Energy
EPA	Environmental Protection Agency
GAO	General Accounting Office
USIJI	U.S. Initiative on Joint Implementation

Criteria and Other Considerations Used in Reviewing and Evaluating Proposed Projects

These criteria and other considerations were published in the June 1, 1994, Federal Register (Vol. 59, No. 104, pp. 28445-28446). They are paraphrased below.

Criteria

1. Is the project acceptable to the government of the host country?

2. Does it involve specific measures to reduce or sequester greenhouse gas emissions initiated as a result of the U.S. Initiative on Joint Implementation or in reasonable anticipation of the Initiative?

3. Does it provide data and methodological information sufficient to establish a baseline of current and future greenhouse gas emissions, both with and without the project?

4. Will it reduce or sequester greenhouse gas emissions beyond those without the project, and, if the project is federally funded, is it or will it be undertaken with funds in excess of those available for such activities?

5. Does it contain adequate provisions for tracking the greenhouse gas emissions reduced or sequestered as a result of the project and, on a periodic basis, for modifying such estimates and comparing actual results with original projections?

6. Does it contain adequate provisions for external verification of the greenhouse gas emissions reduced or sequestered by the project?

7. Does it identify any associated non-greenhouse-gas environmental impacts and benefits?

8. Does it provide adequate assurance that the greenhouse gas emissions reduced or sequestered will not be lost or reversed over time?

9. Does it provide for annual reports to the Evaluation Panel on the emissions reduced or sequestered and on the share of such emissions attributed to each domestic and foreign participant, pursuant to the terms of the voluntary agreement among the project's participants?

Other Considerations

1. Does the project have a potential to lead to changes in greenhouse gas emissions outside the project's boundaries?

2. Apart from the project's effect on greenhouse gas emissions, does the project have any potential positive and negative effects on factors such as local employment and public health?

3. Are U.S. participants who are emitting greenhouse gases within the United States taking measures to reduce or sequester those emissions?

4. Does the host country have efforts under way to (1) ratify the United Nations Framework Convention on Climate Change, (2) develop a national inventory and/or baseline of greenhouse gas emissions and sinks, and (3) reduce its emissions and enhance its sinks of greenhouse gases?

Appendix II

Research on Evaluating Benefits From Joint Implementation Pilot Projects

The awarding of credit for joint implementation projects' results is a basic distinction between the current pilot program and a fully developed program. Under a fully developed program, investors in an approved project could receive credit for that project's results—greenhouse gas emissions reduced or sequestered—and thus offset their own greenhouse gas emissions.

To help ensure that credits are awarded only when warranted, standard methods are being developed for estimating a project's emissions reduction benefits and for measuring greenhouse gas emissions. Tracking a project's side effects (e.g., its impact on the local economy) is also important.

In support of the pilot program, the Environmental Protection Agency's (EPA) Office of Policy is sponsoring studies of these issues, and it currently has a contract and an interagency agreement for further studies. EPA officials said that they expect these studies to help ensure that emissions reductions are properly identified and reported; to gain international approval of the joint implementation concept, including the clean development mechanism provisions of the Kyoto Protocol; and to move the joint implementation concept from its current pilot phase into full implementation.

One key issue currently being studied is estimating a project's emissions reduction benefits. In the context of joint implementation, "additionality" is the term used to describe the project acceptance criteria that are designed to ensure that the proposed project's financing and abatement of greenhouse gas emissions would not have occurred otherwise.[1] Additionality, however, has meaning only relative to an alternative reference point. Determining that reference point requires project developers to construct a hypothetical baseline.

For example, as evidence of emissions additionality, project proposals must present a reference case, which presents projections of emissions levels without the project, and a project case, which estimates emissions levels with the project. In this example, the emissions additionality is the difference between the emissions levels without the project (the hypothetical baseline) and the emissions levels with the project.

[1]In the context of the U.S. Initiative on Joint Implementation, financial additionality refers to project acceptance criteria that are designed to ensure that the financing of a proposed project would not have occurred otherwise, and emissions additionality refers to the project acceptance criteria that are designed to ensure that the reduction in emissions associated with the project likewise would not have occurred.

An EPA contractor, ICF, Inc., has completed a report analyzing how the pilot program has evaluated additionality; the report is currently undergoing peer review. By the end of June 1998, the contractor is expected to review assumptions about emissions made in the reference case scenario and project case scenario for selected approved projects. In addition, the contractor is expected to develop comprehensive guidelines for developing reference case and project case scenario emissions for greenhouse gas mitigation projects. EPA officials said that they will use this study, along with the results of other studies, to determine whether a credible, fair, transparent, and consistent approach to establishing project baselines and determining project additionality can be developed.

A second key issue currently being studied relates to standardized methods for monitoring, evaluating, reporting, and verifying greenhouse gas emissions benefits. Through an interagency agreement with EPA, the Lawrence Berkeley National Laboratory in Berkeley, California, is expected to complete an assessment of these issues by the end of September 1998. Specifically, the laboratory is to develop comprehensive guidelines for monitoring and evaluating projects. These guidelines are to incorporate such principles as cost-effectiveness, transparency, simplicity, technical soundness, and internal consistency. According to the agreement, these guidelines should also be capable of being used by an independent organization for verifying a project's benefits.

Finally, the laboratory is to identify and develop methods for monitoring environmental, socioeconomic, and other benefits associated with a project. These could include the effect on local economic conditions and on air quality and other environmental indicators.

Comments From the U.S. Initiative on Joint Implementation

Note. GAO comments supplementing those in the report text appear at the end of this appendix

U.S. Initiative on Joint Implementation

Reducing Greenhouse Gas Emissions Through International Partnerships

Located at:
Forrestal Building
Room GP-196
1000 Independence Avenue, SW
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Mailing Address:
U.S. Initiative on Joint Implementation
PO-6
1000 Independence Avenue, SW
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June 3, 1998

Mr. Peter Guerrero
Director, Environmental Protection Issues
U.S. General Accounting Office
Resources, Community, and Economic
Development Division
Washington, DC 20548

Dear Mr. Guerrero:

Thank you for sending me GAO's final draft report, entitled Global Warming: Information on the Joint Implementation Pilot Program (GAO/RCED-97-154, Job Code 160422). We appreciate the opportunity to provide GAO comments on this final draft report. The USIJI Secretariat and our interagency advisors have reviewed this final draft report and provided the attached comments for your information and consideration. We appreciate the opportunity to give you these interagency comments prior to issuing this report in final form. Please note that the USEPA has provided it's own separate comments to you, per your separate letter to Administrator Carol Browner.

Furthermore, it appears that some of the Agency comments which were offered to GAO on April 2, 1998, were not incorporated into this draft document. Although I understand the GAO preference for certain writing styles, the attached comments are primarily provided for purposes of accuracy.

If you have any questions regarding these comments, please contact Ms. Duane Lakich of my staff at: tel (202)586-3268; fax (202)586-3485 or 86, email: duane.lakich@hq.doe.gov.

Sincerely,

Robert K. Dixon

Robert K. Dixon, Ph.D.
Director

Attachment

cc: Mr. Bill Roach, GAO

Supporting the Principles and Objectives of the Framework Convention on Climate Change

Phone: 202-586-1288 Fax: 202-586-3485 or 586-3486

Overall Comments:

- In general, we view the report as a balanced assessment of the USIJI program with a useful analysis of the projects and the consideration of those projects by the USIJI Secretariat and the Evaluation Panel.
- When referring to the USIJI Secretariat and the USIJI Evaluation Panel as "the Initiative" please use USIJI (the official name of the organization) instead.
- The introduction of the report should accurately describe the Kyoto Protocol and include the Clean Development Mechanism (please see detailed comments below).
- The title of the report "Global Warming: Information on the Joint Implementation Pilot Program" should reflect the IPCC's 1995 report in which global "warming" is more commonly referred to as global "change," or climate change.

Specific Comments

Page 1

1st Para (edit 1st sentence): Increasing emissions of carbon dioxide, methane, and other heat-trapping greenhouse gases generated by human activity are believed to contribute to global change.
Note: In the 1995 IPCC report, scientists refer to "global warming" as "global change," and in the last five years, the US government has referred to it as "climate change."

See comment 1.

1st Para (edit 3rd, 4th and 5th sentences): The sentences, "Although the details have not yet been worked out, as part of the agreement, the nations that are parties to this agreement may be allowed to work with other nations to achieve reductions in a cost-effective manner. A solution being considered ...," can be rewritten to more accurately to reflect the current state of play and include the Clean Development Mechanism. Suggest the following rewrite:

"Parties to the Protocol may work together to achieve reductions in a cost-effective manner through market-based mechanisms, although the details have not yet been worked out. These include the concept of joint implementation (JI) which would allow industrialized countries to meet their obligations to reduce their greenhouse gas emissions by receiving credits for investing in projects in other industrialized countries. The JI concept is also found in the Protocol's Clean Development Mechanism which allows for credits through investment in projects in developing countries."

Page 2

See comment 2

3rd Para (edit 1st sentence): The USIJI's Evaluation Panel uses nine criteria...
(See overall comments regarding using "Initiative" and USIJI)

Page 3
Suggest a footnote with the following:

See comment 3.

"The USIJI staff has acknowledged that it has not provided standard monitoring guidance to projects, nor reviewed monitoring plans for most projects since most projects are just beginning to be implemented and/or funded. USIJI is a pilot program that is evolving. Monitoring of greenhouse gas emissions and verifying these reductions is work that still needs to be strengthened. The Environmental Protection Agency (EPA) has funded studies to develop standard methods for calculating project baselines and net emissions, specifically."

Now on p. 4
See comment 4

Page 5
2nd Para (insert the following sentence after the 1st sentence): **Ground rules were developed in an interagency process, chaired by the State Department.**

See comment 5.

2nd Para (edit 2nd sentence): Published in final form in June 1994, **after public comment and revision**, these ground rules established a pilot program, which is intended to evaluate possible approaches to joint implementation.

Now on p. 5.

Page 6
3rd Para (edit 3rd sentence to include): "The Clean Development Mechanism" to the list of market-based approaches so that the key sentence at the end of the paragraph would read: "Such approaches include emissions trading, joint implementation **and the Clean Development Mechanism.**"

Now on p. 7.
See comment 6.

Page 10
1st Para (suggest inserting the following at the end of the first paragraph):
USIJI staff explained that in this pilot program, especially in the early rounds, there were differences of interpretation of some of the criteria as applied to specific projects. This is part of the valuable learning process of the pilot program. The most difficult criteria in this regard relates to the concept of "additionality," meaning the likelihood that the emissions reductions would not have occurred with out the project.

Now on p. 8.
See comment 7.

Page 11
1st Para (suggest inserting the following at the end of the first paragraph):
USIJI has streamlined its application procedures; the first and second rounds were conducted annually. Project developers expressed the need to have a quicker turnaround process, and for the last couple of years, USIJI evaluates proposals 3 times per year. The smallest number of proposals came in Round 4, which was the first after the change to shorter periods.

Now on p. 9.
See comment 8

Page 12 (Figure 1)
Suggest including a footnote indicating the change from evaluating proposals more often (i.e., 3 times per year vs annually) which accounts for changes in the number of proposals submitted.

Now on p. 13.

Page 18
2[nd] Para (1[st] sentence): is repetitive (see page 17, 2[nd] paragraph, 5[th] sentence).

Now on pp.18 and 19.
See comment 9.

Page 24 (Appendix 1)
Four other considerations should accurately reflect "exact" language in USIJI guidelines, not a modified version. Please use the following language as stated in the guidelines:

1) The potential for the project to lead to changes in greenhouse gas emissions elsewhere.
2) The potential positive and negative effects of the project apart from its effect on greenhouse gas emissions reduced or sequestered.
3) Whether the US participants are emitters of greenhouse gases within the United States and, if so, whether they are taking measures to reduce or sequester such emissions.
4) Whether efforts are underway within the host country to ratify or accede to the United Nations Framework Convention on Climate Change, to develop a national inventory and/or baseline of greenhouse gas emissions by sources and removals by sinks, and whether the host country is taking measures to reduce its emissions and enhance its sinks and reservoirs of greenhouse gases.

The following are GAO's comments on the letter from the U.S. Initiative on Joint Implementation dated June 3, 1998.

GAO Comments

1. Prior to the Kyoto Protocol, the term "joint implementation" generally was used to describe all projects that were sponsored by developed countries and that were located, and intended to reduce emissions, in another country. The Protocol established the "clean development mechanism" for projects located in developing countries and distinguished them from projects located in developed countries. The Secretariat suggested that we cite the clean development mechanism in the opening paragraph of this report. Because projects accepted into the Initiative, including those accepted in March 1998 (subsequent to the Protocol), are located in both developing countries and developed countries, in this report we use the term "joint implementation" in its more general, pre-Protocol context. However, we have differentiated between these terms (joint implementation and clean development mechanism) in footnote 9.

2. For increased readability, we have used the word Initiative rather than the acronym USIJI when referring to the U.S. Initiative on Joint Implementation. This is explained in footnote 6 of this report.

3. This information appeared in the draft report provided to the Secretariat for comment and, in our judgment, belongs on page 14 of this report.

4. This information appeared in the draft report and, in our judgment, belongs on page 5 of this report.

5. This information appeared in the draft report and, in our judgment, belongs on page 6 of this report.

6. The draft report provided to the Secretariat for comment discussed the differences of interpretation of the criteria. We added footnote 11 to this report to provide additional information on the nature of the areas of "less than clear compliance" with the criteria as reported by the Secretariat in its comments.

7. The draft report discussed the increase in the number of evaluation rounds conducted each year as a reason for the small number of proposals submitted for evaluation in round 4. Based on the Secretariat's comments,

we also included information on the reason for the change in the number of evaluation rounds the Initiative conducts each year.

8. The draft report provided in the text information on the frequency of the evaluation rounds conducted, and the dates of each evaluation round were provided in the table. Therefore, an additional note to the table is not necessary.

9. We determined it was not necessary to list the Initiative's criteria verbatim in the report. However, in response to the Secretariat's comments, we added an introductory statement to appendix I indicating that we have paraphrased the criteria and other considerations used by the Initiative's Evaluation Panel in evaluating proposals.

United States General Accounting Office

GAO

Report to Congressional Requesters

September 1998

CLIMATE CHANGE

Information on Limitations and Assumptions of DOE's Five-Lab Study

GAO/RCED-98-239

GAO

United States
General Accounting Office
Washington, D.C. 20548

Resources, Community, and
Economic Development Division

B-280459

September 8, 1998

The Honorable Larry Craig
The Honorable Chuck Hagel
The Honorable Jesse Helms
The Honorable Frank Murkowski
United States Senate

Human activities, primarily those related to energy production and use, are increasing the concentrations of carbon dioxide and other "greenhouse gases" in the atmosphere. These heat-trapping gases are believed to contribute to global warming, which could lead to future climatic changes. To address the potential consequences of climate change, the United States and other countries have entered into international negotiations and agreements. In October 1997, the administration proposed stabilizing U.S. emissions of greenhouse gases at 1990 levels by no later than 2012. The most recent agreement, known as the Kyoto Protocol, was negotiated in December 1997 in Kyoto, Japan, and calls for even greater reductions in U.S. greenhouse gases.[1] Of the six greenhouse gases covered by the Kyoto Protocol, carbon dioxide is of significant concern for the United States, constituting more than 80 percent of U.S. greenhouse gas emissions in 1996.

Prior to the Kyoto conference, a September 1997 Department of Energy (DOE) study[2] by five DOE national laboratories quantified the potential for energy-efficient and low-carbon[3] technologies to reduce U.S. carbon emissions[4] to 1990 levels by 2010. Among other things, the study (also known as the five-lab study) concluded that an aggressive national commitment to energy-efficient and low-carbon technologies—coupled with an increase in the price of carbon-based fuels of $50 per metric ton[5]

[1]The Kyoto Protocol to the United Nations Framework Convention on Climate Change would require the United States to reduce its anthropogenic, or man-made, carbon dioxide equivalent emissions during the period from 2008 to 2012 to 7 percent below 1990 levels; however, this protocol has not yet been ratified by the U.S. Senate.

[2]Scenarios of U.S. Carbon Reductions: Potential Impacts of Energy Technologies by 2010 and Beyond, Interlaboratory Working Group on Energy-Efficient and Low-Carbon Technologies (Sept. 22, 1997).

[3]Low-carbon technologies can reduce carbon emissions by employing a less carbon-intensive fuel, such as switching from coal to natural gas.

[4]In the laboratories' study, carbon dioxide is measured in units of carbon, defined as the weight of the carbon content of the carbon dioxide molecule (carbon constitutes 12/44 of the molecule).

[5]A metric ton is 1,000 kilograms, or about 2,200 pounds.

—could reduce carbon emissions to the levels they were in 1990, with energy savings estimated to roughly equal or exceed costs. In view of the study's potential influence on U.S. climate change policy, as requested, we are providing you with information on (1) how the study's scope and methodology may limit its usefulness, (2) key assumptions that may have influenced the study's results, and (3) the study's role in the formulation of the October 1997 climate change proposal and the Kyoto Conference's emission-reduction goals for the United States.

Results in Brief

The five-lab study is an important step in evaluating the role that energy-efficient and low-carbon technologies can play in the nation's efforts to reduce global warming gases. However, the study's usefulness is limited because it does not discuss the specific policies needed to achieve its estimate of 394 million metric tons of carbon reductions by 2010 and does not fully consider the costs to the nation's economy of reaching this goal. For example, a policy involving tax credits as an incentive for consumers to make energy-efficient purchases could have different economic and budgetary impacts from a policy requiring manufacturers to meet minimum energy-efficiency levels for products. According to DOE laboratory officials, specifying the types of policies needed to achieve such significant reductions by 2010 was not one of the study's objectives. Furthermore, the study assumes a fee of $50 per ton for carbon emissions, which would increase the cost of energy; however, the study does not evaluate the broader impacts that this cost may have on the economy. DOE laboratory officials acknowledge that the study does not examine the broader economic impacts of such a carbon fee on the U.S. economy but said that, in their opinion, these broader economic impacts would be minor.

The study's finding that the widespread adoption of energy-efficient technologies can be achieved with low to no net cost to the nation is heavily dependent on the assumptions made for four sectors of the U.S. economy—buildings, industry, transportation, and electricity production. Among the groups that we interviewed, we found a disparity of views on key assumptions that may have influenced the study's results. Several of the groups[6] questioned some of these assumptions as being too optimistic, such as those about the payback period, rate of adoption of new technologies, or timing of technological breakthroughs. For example, the study assumes that industry will change the length of time expected for a capital investment to recover its costs—known as the payback

[6]Of the 52 groups that we contacted to obtain views on the energy-efficient and low-carbon technologies in the study, 31 provided their views on the study. App. I provides the details of our scope and methodology, including our selection of these groups. App. II lists the groups.

period—from about 3 years to nearly 7 years. However, most of the representatives of the seven industries that used about 80 percent of the manufacturing energy consumed in the United States in 1994 indicated this assumption may be too optimistic given their current capital constraints, market conditions, and existing manufacturing processes. On the other hand, some groups believed that certain assumptions in the study appear reasonable. For example, the Legislative Director of the International District Energy Association said that the study is not only reasonable, but may underestimate the potential carbon savings that industry might realize by 2010 from new technologies, such as cogeneration power systems that use waste heat to supplement an industry's energy needs.

The study has been cited as one of many documents considered in formulating the administration's October 1997 climate change proposal. Additionally, according to the Department's Assistant Secretary for Energy Efficiency and Renewable Energy, the study was one of the documents considered in formulating the emission-reduction goals for the United States at the December 1997 Kyoto Conference.

Background

The study by five DOE national laboratories[7] was prepared in response to a growing recognition that any national effort to reduce the growth of greenhouse gas emissions must consider ways of increasing energy productivity. According to DOE laboratory officials, project discussions began in the summer of 1996, a peer review committee was formed in November 1996, and official authorization and a budget of $500,000 were provided in December 1996 to "analyze the impact of energy efficiency technology on energy demand growth in the United States." Requested by DOE's Office of Energy Efficiency and Renewable Energy, the five-lab study had a central goal of quantifying the potential for energy-efficient and low-carbon technologies to reduce carbon emissions in the United States by 2010 for four sectors of the U.S. economy—buildings, industry, transportation, and electricity production. The building sector includes residential and commercial buildings, where energy is used for heating and cooling, lighting, refrigeration, cooking, heating water, and operating electrical appliances. The industrial sector includes all manufacturing, as well as agriculture, mining, and construction activities. The transportation sector includes passenger cars and light-duty trucks, freight trucks, railroads, aircraft, and marine vessels. The electricity-producing sector

[7]Argonne National Laboratory, Lawrence Berkeley National Laboratory, National Renewable Energy Laboratory, Oak Ridge National Laboratory, and Pacific Northwest National Laboratory.

includes electric power produced from coal, oil, natural gas, nuclear energy, hydroelectric systems, wind, solar energy, and biomass.

Initially, the study's focus was on energy efficiency from technology and the carbon savings that may accrue from such technologies. Subsequently, DOE laboratory officials said that the study's objectives were expanded about March 1997 to include not only the potential for carbon savings from energy efficiency, but also carbon savings from switching fuel supply options for electric power generation, such as from coal to natural gas. Because it was recognized that few low-carbon technologies would be implemented by the electricity sector without some type of external incentive or regulation, the officials told us that the study's objectives were also expanded to include an assessment of the impact of increasing the price of carbon-based fuels by $25 and $50 per ton.[8] The officials noted that it is not unusual for a study to evolve over time and that the expansion of the study's objectives was in large part due to early comments from peer reviewers.

In calculating the carbon savings that could be achieved for each of the four sectors of the U.S. economy, the study uses three different, increasingly more aggressive, scenarios: (1) an efficiency scenario that assumes the United States takes an active role in public and private efforts to promote energy efficiency through enhanced research and development and market transformation activities; (2) a high-efficiency/low-carbon scenario that assumes a more aggressive national commitment to energy efficiency coupled with a $25 per ton carbon fee; and (3) a high-efficiency/low-carbon scenario that, in addition to the aggressive national commitment to energy efficiency, assumes a $50 per ton carbon fee. As shown in table 1, the study's estimate of carbon savings for the most aggressive scenario is more than 200 percent greater than its estimate for the first scenario.

[8]According to the study, a $50 per ton increase in the price of carbon-based fuels would increase the price of a gallon of gasoline by 12.5 cents, increase the price of electricity produced from natural gas (at 53-percent efficiency) by 0.5 cents per kilowatt-hour, and increase the price of electricity produced from coal (at 34-percent efficiency) by 1.3 cents per kilowatt-hour.

Table 1: Potential Carbon Savings by 2010 Under the Five-Lab Study's Three Scenarios

Metric tons in millions

Economic sector	First scenario	Second scenario	Third scenario	Percent increase[a]
Buildings	25	44	62	148
Industry	28	54	93	232
Transportation	73	88	103	41
Electricity production	[b]	48	136	[b]
Total	126	234	394	213

[a]Compares savings under the third scenario with those under the first scenario.

[b]Unlike the second and third scenarios, the first scenario assumes no carbon savings from fuel switching among utilities to reduce carbon in the production of electricity, such as converting from coal-fired to natural gas-fired power plants

It is important to note that, at numerous points, the five-lab study qualifies its 2010 estimates by noting, among other things, that the calculations generally represent an "optimistic but feasible potential" for carbon savings. In some cases, particularly transportation, major breakthroughs in technologies would be needed to achieve these savings.[9] DOE laboratory officials noted that, with the exception of the transportation sector, they believe the majority of the study's 394 million metric tons of emissions reductions come from technologies that exist now or are near the end of their development phase. For example, the officials said that the 62 million metric tons of carbon emissions reductions estimated for the building sector can be achieved solely from technologies that exist today. Additionally, the officials emphasized that the study was not a projection of what would happen by 2010 but of what could happen if the nation embarked on a path to reduce carbon emissions that included aggressive federal policies and programs, strengthened state programs, and very active private sector involvement, beginning in 2000 and being progressively phased in by 2010.

Limitations of the Study

The five-lab study is an important step in evaluating the role that energy-efficient and low-carbon technologies can play in the nation's efforts to reduce global warming gases, according to several groups that we contacted; however, the study's scope and methodology may limit its

[9]By 2010, scenarios 1 and 2 would achieve only about 32 and 60 percent, respectively, of the 394 million metric tons achieved by the study's most aggressive scenario; unless otherwise specified, assumptions relate to the scenario described as an aggressive national commitment to energy-efficient and low-carbon technologies coupled with a $50 per ton carbon fee.

usefulness. For example, the study does not identify the type of policies that would be needed to get consumers and businesses to reduce carbon emissions by 394 million metric tons by 2010, and it does not indicate how these policies would be implemented. Additionally, the study does not address the broader economic effects on the nation's economy, such as how the $50 per ton carbon fee may affect energy prices, energy consumption; and, eventually, economic activity and employment levels in the rest of the economy.

Unspecified Policies

The study bases its results on a package of unspecified policies that could bring about substantial increases in public and private research and development, acceleration of the adoption and use of energy-efficient technologies, advancement of the timing of postulated technological breakthroughs, and changes in the historical patterns of consumer and industry behavior. However, the study provides few suggestions as to what these policies would be, how they would be designed and implemented, or how they could be paid for. For example, a policy involving tax credits as an incentive for consumers to make energy-efficient purchases could have different economic and budgetary impacts from a policy involving regulations and standards, such as requiring manufacturers to meet minimum energy-efficiency levels for appliances. In its August 1997 peer review comments to DOE, the Treasury Department wrote that the five-lab study does not

"shed much light on what government can or should do to enhance the role technology will play in mitigating the growth of carbon emissions. In particular, the contribution of the report is to document energy savings and emissions reductions that would accrue if U.S. consumers and businesses move closer to the current (and, in some cases, reasonably anticipated) technology frontier. Despite its efforts to justify these moves as 'cost-effective,' the report does not address the policies that would be needed to actually get consumers and businesses to adopt the technologies described in the report, nor does it present a rigorous assessment of the societal costs that would accrue if they did."

In its August 1997 peer review comments to DOE, the Council of Economic Advisors was also critical of the study's failure to present the specific policies that would stimulate the adoption of these technologies. Similarly, according to an October 1997 study,[10] the kinds of policies implemented to achieve any particular target for reducing greenhouse gas emissions "will have a significant impact on the costs." While acknowledging that the

[10] The Economics of Climate Change, S. DeCanio, Department of Economics, University of California at Santa Barbara (Oct. 1997).

types of policies chosen can have an impact, officials of DOE's Office of Energy Efficiency and Renewable Energy noted that, in their view, the main point of the October 1997 study is that there are many policies that could be implemented and have a low, if any, net cost.

DOE laboratory officials agreed that the study does not discuss the policies needed to achieve carbon savings by 2010 but explained that this was not a study objective or task from DOE. However, the officials also noted that there is fairly recent historic precedent for the types of behavior by consumers and industry modeled under the study's most aggressive scenario. For example, the officials said the growth in the demand for energy assumed under this scenario (0.13 percent annually through 2010) is more conservative than the actual growth in demand from 1973 through 1986 when the nation's economy grew by about 35 percent while primary energy demand remained unchanged. Additionally, the American Council for an Energy-Efficient Economy (ACEEE) indicated that the study's message is clearer because its focus on technology is unencumbered by policy discussions.

Other Economic Effects

The study does not address the various broader economic effects on the nation's economy. The study employed a methodology that, in essence, involved adding together the estimated net cost or savings to the economy for the adoption and use of each individual energy-efficient, carbon-reducing technology, with the savings based on the direct cost of adopting these technologies compared to the study's estimated energy savings over the life of these technologies.[11] However, this methodology focuses on one aspect of the economy—energy—and does not consider the broader impacts on other non-energy related aspects of the U.S. economy. Without considering the interrelationships between the changes that the five-lab study proposes—such as imposing a $50 per ton carbon fee—and other sectors of the economy, the full effects of these changes are not known. For example, the study does not include any analysis of the impacts of a $50 per ton carbon fee on energy consumption or economic activities elsewhere in the U.S. economy, including the impacts of these fees on energy prices and energy demand, as well as potential employment impacts. Several of the groups we contacted, such as the Global Climate Coalition and the International Project for Sustainable Energy Paths, believe the lack of an economic "feedback effect" in the study's methodology limits the usefulness of the study's results.

[11]Direct cost includes the incremental cost of investment in the technologies as well as an allowance for the overall cost of a package of programs and policies required to achieve the carbon emissions reductions.

DOE laboratory officials recognized that the study does not address these broader economic feedback effects. In their opinion, these impacts would be minor because only one sector—electricity generation—relies primarily on the increased price of carbon as an economic stimulus to achieve significant carbon reductions. The officials noted that the study assumes that the estimated carbon reductions for two sectors—buildings and industry—rely primarily on more aggressive policies, and for another sector—transportation—the estimated carbon reductions rely on technological breakthroughs. Regarding increased prices for electricity generation, the officials envisioned that the overall net impact of the most aggressive scenario on the nation's economy would be small.[12] Additionally, the officials acknowledged that the study does not provide a quantitative analysis to support their view that the broader effects would be minor. Officials of DOE's Office of Energy Efficiency and Renewable Energy agreed that the full costs to the nation's economy are not considered in the study but emphasized that neither are the full range of benefits from energy-efficient technologies, such as the lower cost of state compliance with Clean Air Act regulations or the decreases in the costs for oil imports.

Disparities in Views About Key Assumptions

The study's calculations of carbon savings depend, in large measure, on the assumptions made about a host of factors in four sectors of the U.S. economy, including assumptions about consumers' purchasing behavior, loan rates, appliance standards, industrial capital constraints, the commercialization of near-term technologies, technological breakthroughs, future costs, and future benefits. Comments from interested and affected parties[13] about the reasonableness of selected assumptions illustrated disparities in their views on some key assumptions, including those on discount rates, capital recovery factors, the rate of adoption of new technologies, the timing of technological breakthroughs, and the impact of changing the electricity-generating sector by 2010.

Discount Rates

The choice of a discount rate is a key assumption because it can affect whether an investment is viewed as cost-beneficial or not. In the five-lab study, the discount rate is used to value the stream of future benefits, such as estimated energy savings, accruing throughout the lifetime of an

[12]According to these officials, the impact of the most aggressive scenario would be less than 0.2 percent for the nation's approximately $10 trillion gross domestic product by 2010.

[13]See footnote 6.

investment. Once these accumulated benefits have been calculated, they are used to determine the cost-effectiveness of a technology (energy savings less added investment cost). The study assumes that only cost-effective technologies will be adopted to achieve the level of carbon reductions estimated for each scenario. Assuming a higher discount rate will, among other things, cause fewer technologies to be viewed as cost-beneficial, whereas a lower discount rate means that more long-term investments with higher initial costs will be viewed as cost-beneficial. The study evaluates costs and benefits from two perspectives. The first, or more optimistic, case uses real discount rates[14] of 7 percent for buildings, 10 percent for transportation, and 12.5 percent for industry. The second case uses higher discount rates—15 percent for buildings and 20 percent for transportation and industry, thus reducing the value of energy savings. According to DOE laboratory officials, the technologies included in the study are cost-effective even with the higher discount rates, and these rates are higher than those recommended by the Office of Management and Budget (OMB) for evaluating the costs and benefits of public policies.

The study's assumed discount rates for the transportation sector were not a significant issue among the groups we contacted; however, some groups were skeptical of the assumption of a 7-percent real discount rate for the building sector. For example, the Association of Home Appliance Manufacturers told us that the consumer discount rate for most replacement appliances, such as refrigerators, clothes washers, clothes dryers, and dishwashers, ranges from 12 to 15 percent. Similarly, officials from the Energy Information Administration (EIA)[15] noted that consumers often charge such items on credit cards where the discount rate would range from about 12 to 16 percent, or more. Representatives of the Global Climate Coalition, National Association of Home Builders, and others also found the study's assumption of a 7 percent discount rate for the building sector too optimistic. Some noted, however, that the 7 percent would be reasonable for appliances included in new home purchases. EIA officials and others also noted that some replacement appliances—such as hot water heaters—are often purchased without regard to energy efficiency or cost-effectiveness. The officials explained that, although water heaters are a significant energy item in most homes, when water heaters fail, consumers rarely calculate a life cycle cost analysis, choosing instead to take what the plumber or local appliance store has most readily available.

[14]Real discount rates have been adjusted for inflation.

[15]EIA is an independent statistical and analytical agency that is required to prepare an annual report containing trends and projections in energy consumption and supply.

Representatives of other groups considered the 7-percent rate for the building sector reasonable and pointed out that rebates and low-interest financing, such as past utility-administered energy-efficiency programs, could lower the effective discount rate on building sector purchases to 7 percent. DOE laboratory officials explained that the 7-percent rate for the building sector would be consistent with a scenario in which the nation embarked on a path to reduce carbon emissions that included aggressive federal policies and programs. Additionally, the officials noted that the higher discount rates that some groups were more comfortable with are still within the range of discount rates that the study's most aggressive scenario concludes are still cost-effective.

Capital Recovery Factors for the Industrial Sector

A key assumption for the industrial sector involves the length of time expected for a capital investment to recover its costs—known as the payback period. The study assumes that, for investment planning purposes, industry can be persuaded to change the length of time expected for a capital investment to recover its costs for energy-efficiency investments from about 3 years to nearly 7 years.[16] Under this scenario, the study assumes industry would install new energy-efficient technologies on twice as many operations as they would normally.

Most of the representatives of seven industries that used about 80 percent of the manufacturing energy consumed in the United States in 1994 indicated that the capital recovery factor assumed for the industrial sector may not realistically consider the capital constraints, market conditions, and existing manufacturing processes these industries operate under today. For example, in a November 1997 letter to the Secretary of Energy, the Chemical Manufacturers Association noted that the study's assumption that the industry could double the rate of capital stock turnover is "impossible or at a minimum, highly improbable." Representatives of the American Petroleum Institute explained that, in a business investment, (1) there is nothing special about energy-efficiency investments; (2) such investments have to compete directly with other investments for limited capital assets; and (3) the longer the payback period, the greater the risk and the uncertainty associated with an investment. Most of the representatives of the seven industries indicated that they would not be able to accept more than a 4-year payback; several said 3 years or less would remain their industry's normal payback period. Generally, the

[16]According to the study, the historical capital recovery factor (or payback period) for energy-efficiency investments by industry is about 33 percent (a 3-year payback); the study assumes that industry will change its capital recovery factor for energy-efficiency investments to 15 percent (nearly a 7-year payback).

representatives said that a 7-year payback is not realistic because of the higher risks and uncertainties associated with longer investments, the competing demands within their firms for investment capital, and their increasingly global competition.

On the other hand, the Director of ACEEE believed that industry could achieve this goal with little difficulty, and pointed out that this is consistent with the Council's 1997 report,[17] which noted that industry often does not fully account for all the savings (both energy and nonenergy) in its financial analyses of such projects. DOE laboratory officials also believed that, given an aggressive package of federal policies promoting low-carbon technologies, along with federal research and development funds, industries would begin to look at such investments more favorably. They noted that for some larger investments—known as strategic investments—industry has been willing in the past to look at payback over a longer period of time. This is consistent, they noted, with a 1986 study[18] which found that the capital budgeting practices of 12 large manufacturers varied based on the size of the project, with large projects having capital recovery rates ranging from 15 to 25 percent (paybacks ranging from about 7 to 4 years, respectively), and small- and medium-sized projects having capital recovery rates ranging from 35 to 60 percent (paybacks ranging from about 3 to less than 2 years, respectively).[19] Many energy-efficiency projects in the industrial sector would be viewed as large projects.

Technology Adoption Rate for the Building Sector

One of the study's key assumptions involves the choice of "penetration rates," or the rates of adoption and use of energy-efficient technologies within a certain time frame. For the building sector, the study assumes a 65-percent penetration rate for its most aggressive scenario. This means that 65 percent of the energy savings achievable from maximum cost-effective energy-efficiency improvements are realized in residential and commercial buildings constructed or renovated from 2000 to 2010 and in the equipment subject to replacement during this time period.

[17]Energy Innovations: A Prosperous Path to a Clean Environment, Alliance to Save Energy, ACEEE, Natural Resources Defense Council, Tellus Institute, and Union of Concerned Scientists (June 1997).

[18]Capital Budgeting Practices of Twelve Large Manufacturers, M. Ross (Winter 1986).

[19]According to DOE, under the most aggressive scenario, investments in energy-efficient technologies would be on the lower end of the range (15 percent for large projects and 35 percent for small- and medium-sized projects).

Among the groups we contacted, we found a disparity of views on the reasonableness of the assumed 65-percent penetration rate. Several were skeptical of this level of penetration and questioned its reasonableness for some categories of new and retrofitted structures—such as low-cost, or entry-level, housing and rental properties. For example, the National Association of Home Builders told us that the entry-level housing market is extremely cost-sensitive and questioned whether builders of these structures would install the higher initial cost but more energy-efficient technologies described in the five-lab study. They were also skeptical that such homes would be equipped with higher initial cost, but more energy-efficient appliances. Similarly, the Air-Conditioning and Refrigeration Institute noted that the study's assumption of a 65-percent penetration rate is unrealistic, noting that generally "the people making the purchasing decision of air conditioning equipment are usually not the ones who will be paying the energy bills, so first cost becomes more important than operating cost."

Conversely, officials from the Alliance to Save Energy and ACEEE said that, in their view, the study's assumptions for the building sector are probably conservative. The officials said that, in the building sector, such things as aggressive national codes and standards over the home building industry and significantly higher energy-efficiency standards for appliance manufacturers could achieve the level of carbon emissions reductions estimated in the study. DOE laboratory officials noted that the 65-percent penetration rate was based on retrospective studies and their judgment of the percentage of cost-effective technologies that can reasonably be adopted over time with strong policy incentives. Additionally, the officials said that the 65-percent penetration rate for the building sector is conservative in their opinion because their analysis of this sector does not rely on any technological breakthroughs.

Timing of Technological Breakthroughs for the Industrial and Transportation Sectors

Some industry groups we talked with questioned the study's assumptions about the feasibility of some technologies being available by the 2010 time frame, noting that, in a few cases, the study's description of these technologies as "incremental" is incorrect because they still require fundamental breakthroughs. For example, according to officials of The Aluminum Association, the study's assumption that the aluminum industry will be able to use inert anode[20] technology to cost effectively smelt aluminum by 2010 is overly optimistic, with a more realistic time frame for

[20]According to the February 1998 Inert Anode Roadmap, there are a number of barriers to the use of this technology, with some of the most critical barriers being the durability and longevity of the anode material, which fails to maintain the thermal and chemical properties needed.

implementing this breakthrough technology being 2020. To be cost-effective, the officials explained, anodes must last for 8 to 10 years, but anode life in ongoing experiments has ranged from a matter of hours to several weeks.

Similarly, some groups were skeptical that the breakthrough technologies envisioned for the transportation sector will be forthcoming soon enough to substantially reduce carbon emissions by 2010. According to representatives of the American Automobile Manufacturers Association (AAMA), the technology relied on for much of the carbon savings envisioned for light-duty vehicles is not expected to be available as quickly as the study assumes, and even if the technologies are demonstrated as viable, the benefits will probably not be realized until after 2010. For example, a substantial amount of the assumed reduction in light-duty vehicles' carbon emissions is expected to come from lean-burn engines that improve fuel economy but produce excessive amounts of nitrogen oxide, a Clean Air Act-regulated pollutant and an ozone precursor. According to AAMA officials, these engines still require significant technological development before they can be used in the U.S. market. They said that U.S. automotive manufacturers have been working on this type of engine for over 20 years, and—while it is technically feasible—it is still a question of technological cost-effectiveness today. They also pointed out that the median expected lifetimes of passenger cars and light-duty trucks—now about 14 and 16 years, respectively—are increasing, making it more difficult to achieve part of the carbon reductions estimated for the transportation sector by 2010. Officials of DOE's Office of Energy Efficiency and Renewable Energy noted that longer vehicle lifetimes will slow the pace of technological change but emphasized that the study scenarios consider these extended lifetimes.

The AAMA representatives and others pointed out that the study acknowledges that transportation sector reductions are not likely to materialize without a major change in U.S. policy to foster transportation modes that are more energy-efficient, as well as an intensification of research efforts. With respect to transportation sector technologies, the study cautions that

"because the outcomes postulated in the high-efficiency/low-carbon scenario require technological breakthroughs, they require a certain degree of luck to be achieved by 2010. There are no credible methods to accurately gauge the probability of such breakthroughs; we believe they stand a decent chance of occurring with an intensification of research efforts, but we stop short of claiming that they are a likely outcome of such an intensification."

DOE laboratory officials acknowledged that, in some areas such as the transportation sector, technological breakthroughs will be needed but noted that it is plausible that additional funding for research and development activities could accelerate such breakthroughs. Additionally, officials of DOE's Office of Energy Efficiency and Renewable Energy noted that the study's most aggressive scenario does not anticipate that fuel cell vehicles will enter the market until 2007, yet, according to DOE, a number of manufacturers, including Daimler Benz, have announced that they plan to have such vehicles on the road before 2007. Also, according to DOE, Toyota has announced that it plans to introduce a hybrid vehicle in the U.S. market in 2000, several years ahead of the entry year assumed in the study's most aggressive scenario. Furthermore, officials from the American Forest and Paper Association said the assumptions about some breakthrough technologies for their industry, such as impulse drying, multiport cylinder drying, and on-machine sensors, are reasonable.

Changes in the Electricity Sector

Some groups believed the study's assumptions about changes that would occur in the electricity sector may be too optimistic. For example, the study's cost-benefit analysis assumes that a large segment of the electricity-generating sector can change from coal to natural gas without causing the price of natural gas to increase. However, officials from EIA, the American Petroleum Institute, and the Edison Electric Institute said that it is optimistic to assume that significant switching from coal to natural gas can occur without resulting in an increase in gas prices. DOE laboratory officials explained that this could happen due partly to the study's assumed reduction in overall energy demand for the building sector, after this sector adopts more energy-efficient technologies, such as highly efficient windows, doors, and appliances.[21] One group questioned whether the assumed carbon savings would occur. A June 1998 American Petroleum Institute report[22] asserts that a $50 increase in the price of carbon-based fuels would not cause coal plants to convert to natural gas, and that—in order to achieve such conversions—the five-lab study further assumes that coal plants incur an additional environmental compliance cost of $1,400 per ton for nitrogen oxides and $100 per ton for sulfur

[21] By 2010, the study assumes that the building sector's energy demand decreases by about 5 percent, or about 2 quads, from 1997 levels, for the most aggressive scenario.

[22] A Critique of the "Five Lab" Study, R. Sutherland, American Petroleum Institute (June 23, 1998).

dioxides.[23] DOE laboratory officials disagreed with this report and emphasized that the five-lab study's analysis of opportunities to convert coal plants to natural gas was based on a detailed plant-by-plant assessment of conversion costs.

Study's Role in Formulating Policy

In October 1997, the administration announced key elements of its proposal to reduce the emissions of greenhouse gases to the levels they were in 1990 by no later than 2012, with additional reductions below the 1990 levels in the ensuing 5-year period. Among other things, this proposal provided the framework for the level of greenhouse gas emissions reductions that the United States would commit to achieve in the next international negotiation to be held in December 1997 in Kyoto, Japan. Unlike the 1992 international climate change agreement that had called for voluntary reductions, the Kyoto conference was to establish binding commitments for reductions in greenhouse gases.

In the administration's October 1997 proposal, the five-lab study was cited as illustrating how greater use of many existing technologies could reduce carbon emissions. Also, the OMB Associate Director of Natural Resources, Energy and Science, told us that the administration relied on several key studies, including the five-lab study, in determining which activities should be a part of the administration's climate change initiatives. According to the five-lab study, the estimated amount of carbon that the United States would need to reduce in order to meet 1990 levels by 2010 is 390 million metric tons per year. The study found that, for its most aggressive scenario, the United States could reduce its emissions by 394 million metric tons by 2010 with a low to no net cost to the economy. According to the Principal Deputy Assistant Secretary for Energy Efficiency and Renewable Energy, the five-lab study increased in its importance as support for the administration's climate change proposal when, in June 1997, a major study[24] dealing with the economic effects of global climate change policies could not be finalized.

In its December 1997 Kyoto Protocol negotiations, the United States agreed—subject to Senate ratification—to reduce the emissions of six

[23]DOE officials pointed out that the study also analyzes the impact of lower costs of $700 per ton for nitrogen oxides and no additional costs for sulfur dioxides. Using EIA's forecasted 2010 prices for coal and natural gas, however, shows that the incremental carbon reductions are less than one-third of the amount removed when the higher costs are assumed.

[24]Draft report, Economic Effects of Global Climate Change Policies: Results of the Interagency Analytical Team (June 1997).

greenhouse gases[25] to 7 percent below 1990 levels.[26] However, one greenhouse gas—carbon dioxide—is by far the largest contributor to total U.S. greenhouse gas emissions, constituting more than 80 percent of total U.S. emissions in 1990 and projected to represent more than 80 percent in 2010. With its technological focus on the ability of the nation to significantly reduce carbon emissions, the five-lab study was also one of the key documents cited as support for the December 1997 Kyoto Protocol's emission-reduction commitments for the United States, according to DOE's Assistant Secretary for Energy Efficiency and Renewable Energy.

Agency Comments

We provided a draft of this report to the Department of Energy (DOE) for review and comment. The agency generally agreed with the overall message of the report, noting that it showed reasonable balance and was consistent with information DOE had received following publication of the five-lab study. DOE suggested several changes to clarify information in the report. For example, the agency suggested that we note in the section on other economic effects that, while the five-lab study did not consider the full range of costs to the nation, it also did not consider the full range of benefits of employing these energy-efficient and low carbon technologies, such as a lower cost of compliance with Clean Air Act regulations. We made this change and incorporated DOE's other comments where appropriate.

The agency expressed concern with the section on the study's limitations. While noting that the agency did not disagree with the two principal limitations presented in our report, DOE suggested that we state in that section that these limitations do not invalidate the conclusions of the five-lab study, most notably the study's essential conclusion that "a vigorous national commitment to develop and deploy energy efficient and low-carbon technologies has the potential to restrain the growth of U.S. energy consumption and carbon emissions . . . and can produce energy savings that are roughly equal to or exceed costs." We did not make this change, however, because the types of policies that might be needed to actually get consumers and businesses to adopt the technologies described in the report are not specified, and some have expressed concerns about the costs of these policies. For example, the Treasury

[25] Carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexaflouride.

[26] According to the Chair of the Council of Economic Advisors, after accounting for changes in the definition of the baseline for three of the six gases from 1990 to 1995 and the way that carbon sinks are figured, the actual reduction is no more than 2 to 3 percent more than the administration originally proposed as a negotiating position.

Department questioned the study's conclusion that carbon emissions can be reduced in ways that reduce energy costs more than they increase other societal costs, noting that in its view the study "substantially understates the costs of government policies to promote technology." Additionally, as noted in the section on key assumptions, the study's finding that a widespread adoption of energy-efficient technologies can be achieved with a low to no net cost to the nation is heavily dependent on the assumptions made, and we found a disparity of views on some of the key assumptions that may have influenced the study's results.

DOE also suggested that we include in our report that, since publication of the five-lab study, the administration has provided many of the elements of the policy roadmap in its announcement of a Climate Change Technology Initiative, which is a combination of higher budgets for technology research and tax incentives to accelerate the use of energy-efficient and low-carbon technologies. We did not include this in our report, however, since this initiative was outside the scope of our review. Also, in our April 1998 report Department of Energy: Proposed Budget in Support of the President's Climate Change Technology Initiative (GAO/RCED-98-147, Apr. 10, 1998), we raised several questions regarding DOE's proposed budget that the Congress may want DOE to address before the agency implements this initiative. Additionally, uncertainties regarding the lack of specific performance goals associated with this initiative were discussed in our June 1998 testimony Global Warming: Administration's Proposal in Support of the Kyoto Protocol (GAO/T-RCED-98-219, June 4, 1998).

DOE also questioned the relevancy of including comments from organizations that criticized some assumptions of the five-lab study as optimistic when compared to current conditions. We believe the viewpoints of these organizations are relevant and appropriately reflect their opinions of the reasonableness of certain key assumptions used in the study, taking into consideration current conditions and historical trends. Appendix III contains the full text of the agency's written comments and our responses.

We conducted our review from December 1997 through August 1998 in accordance with generally accepted government auditing standards. A detailed discussion of our scope and methodology is provided in appendix I.

As arranged with your offices, unless you publicly announce its contents earlier, we plan no further distribution of this report until 15 days after its date. At that time, we will send copies of the report to the Secretary of Energy and other interested parties. We will also make copies available to others upon request.

Please call me at (202) 512-6111 if you or your staff have any questions. Major contributors to this report are listed in appendix IV.

Peter F. Guerrero
Director, Environmental
Protection Issues

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Contents

Abbreviations

AAMA	American Automobile Manufacturers Association
ACEEE	American Council for an Energy-Efficient Economy
API	American Petroleum Institute
DOE	Department of Energy
EIA	Energy Information Administration
GAO	General Accounting Office
OMB	Office of Management and Budget

Appendix I

Objectives, Scope, and Methodology

In view of the Department of Energy's (DOE) five-lab study's potential influence on U.S. climate change policy,[1] Senators Larry Craig, Chuck Hagel, Jesse Helms, and Frank Murkowski asked us to provide information on (1) how the study's scope and methodology may limit its usefulness, (2) key assumptions that may have influenced the study's results, and (3) the study's role in the formulation of the October 1997 climate change proposal and the Kyoto Conference's emission-reduction goals for the United States.

To obtain information on the study's limitations and assumptions, we obtained and reviewed the final study, drafts of the study, and intramural and extramural peer reviewers' comments on drafts of the study. We also reviewed DOE's Energy Information Administration's (EIA) 1997 Annual Energy Outlook, which served as the principal basis for the estimated 2010 carbon emission levels under the five-lab study's business-as-usual case,[2] and we discussed various assumptions in the study with EIA officials associated with the development of the 1997 Annual Energy Outlook, as well as EIA's more recent 1998 Annual Energy Outlook. Additionally, we interviewed officials and obtained documents from Oak Ridge National Laboratory and Lawrence Berkeley National Laboratory, the two key laboratories in developing the study. We also contacted 52 organizations that we selected as being interested and affected parties, many with energy-efficiency expertise or able to offer informed opinions about the study's assumptions and limitations based on a particular field of expertise. In selecting these representatives, we contacted potentially interested and affected parties that were identified as being knowledgeable of the study, as well as energy-efficiency, industry, and environmental experts and other groups we identified from Internet searches, discussions with energy-efficiency experts, and our previous experiences. We selected organizations that represent different aspects of the four sectors of the U.S. economy discussed in the study—buildings, industry, transportation, and electricity production—as well as environmental groups. Not all of the representatives we contacted had read the study or wanted to express their views on it. Others had read and analyzed only those parts of the study that related to their sector, and they limited their comments accordingly. Of the 52 groups contacted, 31 commented on one or more aspects of the study. A list of the groups

[1] Scenarios of U.S. Carbon Reductions: Potential Impacts of Energy Technologies by 2010 and Beyond (Sept. 22, 1997).

[2] The study bases its savings estimates on the amount of carbon that would be emitted in 2010 if the nation continued on its current energy consumption and production path. This approach is generally known as the business-as-usual scenario.

commenting appears in appendix II. Additionally, while we discussed some aspects of the assumptions associated with the engineering-economic modeling approach used in some parts of the study, we did not attempt to verify the adequacy of these models or the alterations made to them for analyzing various study scenarios, such as the alterations of EIA's National Energy Modeling System model.

To describe the extent to which the final report's results were reflected in the October 1997 climate change proposal and the December 1997 Kyoto Conference's greenhouse gases emission-reduction goals for the United States, we relied on interviews, memorandums, press, and other briefings by the administration that cited the study as partial support for these proposals, the proposal and conference documents themselves, and testimony before the U.S. Senate. We conducted our review from December 1997 through August 1998 in accordance with generally accepted government auditing standards.

List of Nonfederal Groups Commenting on the Five-Lab Study

Air-Conditioning and Refrigeration Institute
Alliance to Save Energy
American Automobile Manufacturers Association
American Council for Capital Formation
American Council for an Energy-Efficient Economy
American Forest and Paper Association
American Foundrymen's Society
American Iron and Steel Institute
American Metalcasters Consortium
American Petroleum Institute
Association of Home Appliance Manufacturers
Chemical Manufacturers Association
Consumer Energy Council of America/Research Foundation
Edison Electric Institute
Environmental and Energy Study Institute
Global Climate Coalition
International District Energy Association
International Project for Sustainable Energy Paths
National Association of Home Builders
National Association of Manufacturers
National Hydropower Association
National Mining Association
Natural Gas Supply Association
Natural Resources Defense Council
Nuclear Energy Institute
Primary Glass Manufacturers Council
Reason Public Policy Institute
Renewable Fuels Association
Resources For the Future
Steel Founders Society of America
The Aluminum Association

Comments From the Department of Energy

Note: GAO comments supplementing those in the report text appear at the end of this appendix.

Department of Energy
Washington, DC 20585

July 27, 1998

Mr. Peter F. Guerrero, Director
Environmental Protection Issues
United States General Accounting Office
Washington, DC 20548

Dear Mr Guerrero:

Climate Change: Information on Limitations and Assumptions of DOE's 5-Lab Study (GAO/RCED-98-239, Code 160422)

Now on pp. 2 and 3

Thank you for the opportunity to comment on the draft report, "*Climate Change: Information on Limitations and Assumptions of DOE's 5-Lab Study*." For the most part, the report shows reasonable balance in its overall conclusions. Throughout the report, a diversity of views is noted on the one hand, some organizations found the 5 Lab study's assumptions to be too optimistic while on the other hand, some organizations felt that the 5-lab study underestimated the potential for carbon savings (pp. 3-4 and elsewhere). This is consistent with views expressed by various organizations in press releases and newsletter articles following publication of the report.

DOE does not disagree per se with the two principal limitations noted in the "Results in Brief" that "the study's usefulness is limited because it did not identify the policies needed to achieve its estimate of 394 million metric tons of carbon reductions by 2010" and that it "did not fully consider the costs to the nation's economy of reaching this goal." (pp 2-3). Both of these limitations are noted in the 5-Lab Report. However, while these may be "limitations" of the study, the GAO report should state in the Results in Brief section that these "limitations" certainly do not invalidate the conclusions of the study. In fact, the GAO should clearly acknowledge in this section that the essential conclusion of the report, that "a vigorous national commitment to develop and deploy energy efficient and low-carbon technologies has the potential to restrain the growth of U S. energy consumption and carbon emissions. .and can produce energy savings that are roughly equal to or exceed costs" (5 Lab Study Executive Summary). What is at issue is the nature of the policies needed and the total macroeconomic costs of the reductions - <u>not the basic conclusions of the study.</u>

With regard to the nature of the policies, the GAO report repeatedly criticizes the 5 Lab Study for not specifying the precise policies needed to achieve the three carbon reduction scenarios. That fact is indeed a limitation and certainly worth noting. However, as stated clearly in the study, the purpose of the study was to assess the feasibility of major carbon emissions reductions through aggressive technology scenarios. The absence of a roadmap of specific policies does not in any way invalidate the conclusions of the study - especially since the study did consider a wide range of policy implementation costs in the calculation of overall costs and benefits (5 Lab Study pp. 1-11 to 1-15 and Appendix A-2). It should also be noted that since the publication of the study, the Administration has indeed provided many of the elements of the policy roadmap in the announcement of the Climate Change Technology Initiative - a combination of higher budgets for

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technology RD&D and tax incentives to accelerate the use of highly efficient and low-carbon technologies This initiative, if enacted, will provide many of the actions and incentives to accelerate the use of energy efficient and low-carbon technologies that indeed can reduce carbon emissions at low cost.

With regard to the full costs to the nation's economy not being considered, the study acknowledges that a full macroeconomic analysis was not performed. However, the GAO report should also acknowledge that the study did also not consider the full range of benefits of these technologies. In particular, the scenarios would produce such benefits as lower cost of state compliance with Clean Air Act regulations, decreases in oil import costs (and hence less negative U.S. balance of trade), increased electricity system reliability (and therefore decreased costs of power outages) and possible increased public health due to concomitant reductions in emissions of NOx, sulfur, particulates and ozone While it is quite difficult to quantify these benefits, many studies have suggested that the benefits are real and substantial.

Now on p 13.

Several times in the GAO report, organizations appear to criticize the 5-Lab Report for not reflecting current conditions (e.g., top of p. 17). In particular, assumptions on discount rates, capital recovery factors and technology penetration rates are cited as optimistic given current conditions DOE does not believe these comments are relevant The point of the entire 5 Lab Study is to describe what could happen under conditions which deviate from today's situation – i.e., where there's an aggressive national commitment to energy efficiency, including a $50 per ton carbon fee So by design the assumptions differ from a business as usual view of the future These assumptions are well grounded in historical experience of what is indeed possible and the study states in several places that achieving these scenarios will be challenging, but is possible with a sustained national commitment

The following more specific comments are offered

Now on p. 6.
See comment 1.

- The major point of the DeCanio study is not that "the kinds of policies implemented to achieve any particular greenhouse gas emission reduction target "will have a significant impact on the costs" (p. 8) His main point is that there are many policies that could have very low, if any, net costs. The DeCanio article supports this position through illustrations and by citing the Economists' Statement on Climate Change that "For the United States in particular, sound economic analysis shows that there are policy options that would slow climate change without harming American living standards, and these measures may in fact improve U.S productivity in the longer run." These additional points should be noted.

Now on p. 9.
See comment 1.

- Change "transportation and industry" to "transportation" on p 11 Some organizations did express disagreement with the discount rates used for industry, as described in the subsequent section on capital recovery rates.

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Now on p. 8.
See comment 1.

- Change "more than" to "approximately" in footnote 13, p 10

Now on p. 11
See comment 4.

- Insert the following material after the first sentence in the section on "Technology adoption rate" on page 14. "The study's adoption rate for the transportation sector was not a significant issue among the groups we contacted." DOE assumes this is the case since adoption rates for transportation are not discussed in the GAO report and because the 5-lab study is quite conservative in this regard

Now on p. 12.
See comment 5.

- Eliminate the following phrase at the top of p 15: "and questioned whether builders of these structures would install the most energy efficient technologies available." The 5-Lab Study does not assume that the most energy efficient technologies will be installed. Therefore this comment is irrelevant

Now on p. 11.
See comment 6.

- At the top of p. 14 the GAO report fails to note that Marc Ross identified the lower discount rates as applicable to "strategic" investments--i.e., 15% for large projects (not 15 to 25%) and 35% for small to medium projects (not 35 to 60%) DOE believes this should be noted by GAO since the 5-Lab Study characterized its most aggressive scenario as one where energy investments are viewed as strategic

Now on p. 13.
See comment 7.

- At the bottom of p 16, the AAMA suggests that the longevity of passenger cars and light duty trucks is increasing (now about 14 and 16 years, respectively), "making it more difficult to achieve part of the carbon reductions estimated for the transportation sector by 2010" But the 5-Lab Study's analysis explicitly uses the lifetime of vehicles as a parameter in the NEMS model--the longer the lifetime (as is the trend), the slower the pace of technological change Therefore, how could the extended lifetime of vehicles make the carbon reductions more difficult to achieve? The scenarios are based on these extended lifetimes

Now on p 14.
See comment 8

- Eliminate the following sentence from the bottom of page 17: "However, officials from EIA, the American Petroleum Institute, and the Edison Electric Institute said that it is optimistic to assume that significant switching from coal to natural gas could occur without an increase in gas prices." The sentence is not correct (i e , higher gas prices would discourage shifts from coal to gas) and it is placed between two sentences that to belong together.

Now on p. 14.
See comment 9.

- Please insert the following sentence at the bottom of the section on "Timing of Technology Breakthrough" on page 17: "For example, they note that the study does not anticipate vehicles with fuel cells entering the market before 2007 in the most aggressive case, yet a number of manufacturers, including Daimler Benz, have announced that they will have such vehicles on the road before then." In addition, Toyota has announced it will introduce its Prius hybrid vehicle in the U.S. in 2000, several years ahead of the entry year described in the 5-Lab Study's most aggressive scenario "

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Now on p. 15.
See comment 10.

- Change the sentence above "Study's Role in Formulating Policy" on p. 18 to read: "DOE laboratory officials disagreed with this report, and emphasized that the 5-Lab Study's analysis of opportunities to convert coal plants to natural gas combined cycle plants was based on a detailed plant-by-plant assessment of conversion costs." The API report was not based on such a detailed analysis.

Now on pp. 14 and 15.
See comment 11

- Earlier in that same paragraph on p. 18, the GAO report notes only the high end of the externality values that were considered. The sentence should be changed to show the ranges of $700 to $1400 per ton for nitrogen oxides and 0 to $100 per ton for sulfur dioxide.

We do hope you will revisit the areas indicated in your report and consider our viewpoint before proceeding with your final version. Thank you again for affording the DOE the opportunity to comment on your drafted report.

Yours truly,

Eric C. Petersen, Acting Director
Office of Budget, Planning and Customer Service
Office of Energy Efficiency and Renewable Energy

The following are GAO's comments on the Department of Energy's letter dated July 27, 1998.

GAO Comments

1. We agreed with this comment and have revised the report accordingly.

2. See comment 1.

3. See comment 1.

4. The statement suggested by DOE has not been included because this section of our report only addresses the building sector and because the adoption rate of new technologies for the transportation sector was questioned by officials of the American Automobile Manufacturers Association.

5. This sentence was clarified to note that, because the entry-level housing market is so cost-sensitive, the National Association of Homebuilders questioned whether builders of entry level housing would install the higher-initial-cost but more energy-efficient technologies described in the study.

6. The study in question does not use the term "strategic investments" to describe the capital budgeting practices of firms, as suggested by DOE. The study does indicate that the capital budgeting practices of firms varied based on the size of the project, with large projects having capital recovery rates ranging from 15 to 25 percent, medium-sized projects, from 25 to 40 percent, and small projects, from 35 to 60 percent. We have added a clarifying note that DOE's interpretation of the study in question is that, under the most aggressive scenario, investments in energy-efficient technologies would be on the lower end of the range (according to DOE, about 15 percent for large projects and 35 percent for small- and medium-sized projects).

7. DOE's views have been added to this section of the report.

8. Due to a typographical error in the draft sent to DOE, the words "resulting in" were omitted, which distorted the meaning of the sentence. We have revised the report accordingly.

9. The information suggested by DOE has been added to this section of the report.

10. Although our draft report already noted that DOE laboratory officials disagreed with the American Petroleum Institute report, we added DOE's suggested language about the analyses supporting the five-lab study's assessment of conversion costs.

11. We agreed with this comment and have added a clarifying note to this section of our report.

Appendix IV

Major Contributors to This Report

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CBO MEMORANDUM

CLIMATE CHANGE AND THE
FEDERAL BUDGET

August 1998

CONGRESSIONAL BUDGET OFFICE
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WASHINGTON, D.C. 20515

NOTE

Numbers may not add up to totals because of rounding. All years are fiscal years unless noted otherwise.

PREFACE

This Congressional Budget Office (CBO) memorandum was prepared at the request of the Senate Committee on the Budget to document current U.S. efforts in the area of global climate change and to review current federal spending programs and tax policies that relate to climate change. The memorandum also describes proposals contained in the President's 1999 budget for funding for those programs and several new tax policies. It should be helpful to policymakers as they consider options to respond to international proposals for reducing the threat of climate change. In accordance with CBO's mandate to provide objective and impartial analysis, the memorandum contains no recommendations.

Roger Hitchner, Patrice Gordon, and Lesley Frymier of the Natural Resources and Commerce Division and Pearl Richardson of the Tax Analysis Division prepared this memorandum under the supervision of Jan Paul Acton and Frank Sammartino. Perry Beider, Kim Cawley, Kathy Gramp, David Moore, Diane Lim Rogers, and Natalie Tawil, all of CBO, provided useful comments. Melissa Burman edited the manuscript, and Sherry Snyder proofread it. Angela Z. McCollough and Rae Wiseman prepared the memorandum for publication. Laurie Brown prepared the electronic version for CBO's World Wide Web site (http://www.cbo.gov).

June E. O'Neill
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CHAPTER 1

CLIMATE CHANGE: THE POLICY CHALLENGE AND CURRENT PROGRAMS

For over a decade, scientists and policymakers worldwide have debated how human activity affects the global climate and whether anything can or should be done about it. Some people believe that climate change poses a great risk to future generations and call for immediate action that could impose high costs on the economy and society at large. Other people believe that it is not a serious problem and can be dealt with if and when it occurs. Still others believe that the warmer temperatures that coincide with climate change might benefit the economy. Opinions about climate change reflect the uncertainties that surround it: about the science of the phenomenon itself; about the implications for people, economies, and ecosystems; and about the best policy for dealing with it. Further research can help inform policymakers but, as with other highly charged issues, decisions will have to be made before all the facts are in.

Since the mid-1980s, the United States has funded scientific research and monitoring efforts and participated in international negotiations and agreements, all centered around the global climate issue. In 1993, the government developed a set of voluntary programs to cut emissions of carbon dioxide and other greenhouse gases that scientists believe to be at the core of the problem.

But stronger measures would be needed to cut emissions significantly. In December 1997, representatives from the United States and other industrialized countries agreed to the Kyoto Protocol—a treaty with binding targets and timetables for reducing emissions of carbon dioxide and other greenhouse gases.[1] The reductions that the participants agreed to are a modest first step toward a goal of eventually stabilizing atmospheric concentrations of those gases, but some analysts believe that even those preliminary measures will be excessively costly to the U.S. economy.

The Kyoto Protocol requires ratification by the Senate. The Administration is postponing presentation of the Kyoto Protocol to the Senate to get "meaningful participation" from developing countries in the effort to limit emissions—something lacking in the treaty. Climate change is a global problem, and the United States and other industrialized countries will not succeed without global cooperation. Talks with developing countries are ongoing.

1. Kyoto Protocol to the United Nations Framework Convention on Climate Change, FCCC/CP/1997/L.7/Add.1, Conference of Parties, Third Session, Kyoto, December 1-10, 1997 (available at http://www.unfccc.de/fccc/docs/cop3/07a01.pdf).

Even if some level of global cooperation is achieved and the treaty is presented to the Senate, the debate on climate change will have just begun. Policymakers face questions for which there are no certain answers: Should current sacrifices be made for uncertain future benefits? Who should pay for reductions in emissions? and What actions could lessen adjustment costs? If the treaty is ratified, future Congresses will have to consider authorizations and appropriations for particular programs to meet the treaty's targets and timetables.

This memorandum reviews current and proposed federal spending programs and tax policies that relate to climate change, their effects on the federal budget, and the Administration's proposals for funding them. Included in that inventory are activities that directly address climate change and those that are associated with climate change through their effects on emissions of carbon dioxide.

Federal regulatory activities could also affect climate change but are not included in this memorandum. The private sector bears most of the cost of regulation, so those figures do not show up in the federal budget; even the expenses of federal agencies to administer and enforce regulations are often offset by collections from the regulated industry and, hence, have little or no net budgetary impact. Although some regulations may affect energy use and emissions of carbon dioxide, none directly address climate change. That could change as policies evolve.

Sooner or later, policymakers will face major decisions on climate policy—particularly whether to limit carbon emissions and how to go about it. Those policy decisions will inevitably affect the budget. Sharply limiting emissions would have large near-term effects on the economy with ensuing consequences for federal revenues and outlays. The choice of a policy instrument could also have a large budgetary effect. Taxes to curtail use of fossil fuels, for example, could generate substantial revenues. The budgetary effects of tradable emissions allowances—a policy option in the Kyoto treaty—would depend on whether permits were distributed or auctioned. Ultimately, policy decisions that may be influenced by budgetary effects will be dominated by the larger question of the effects of policy actions, or of taking no actions, on the U.S. and world economies.

"DIRECT" AND "ASSOCIATED" SPENDING PROGRAMS AND TAX POLICIES

Programs and tax policies reported in this memorandum are divided into two categories, based on whether they are directly related to climate change or just associated with it. The first category includes spending programs and tax policies that are specifically designated by the Administration as climate change programs. The second category comprises programs that may affect climate change even though that may not be their primary purpose. Some of those programs may be intended to cut the use of fossil fuels—a goal shared with activities that are identified as climate change programs. Others—particularly certain tax policies—may lead to an increase in the use of fossil fuels and thus contribute to carbon emissions, although, again, that is not their purpose.

The direct category comprises spending programs in the U.S. Global Change Research Program (USGCRP), the Climate Change Technology Initiative, and several international programs related to climate change. Budget authority for those programs in 1998 totals $2.9 billion (see Table 1). The USGCRP, which consists mainly of programs to discern the science and consequences of global change, was funded at about $1.9 billion in 1998—roughly 65 percent of funding for programs directly related to climate change. The President requested a substantial increase in 1999, to $3.4 billion, for all climate change programs, mostly for research and development in energy technology.

The Climate Change Technology Initiative also contains proposed changes in tax law. Those changes include several tax credits to encourage the development and adoption of new energy-efficient technologies in transportation, industry, buildings, and electricity. Estimated revenue losses associated with those tax proposals are $478 million in 1999, rising to nearly $1.3 billion by 2003. Those policy proposals and tax policies are discussed in more detail in Chapter 2.

The second category of programs are those associated with climate change primarily through their effects on the use of fossil fuels. Table 1 shows spending for a number of such programs, mostly in the areas of transportation, energy conservation, and nuclear energy research and development. Budget authority totals nearly $1.8 billion in 1998, and the request for 1999 is roughly the same. Those programs are discussed in more detail in Chapter 3.

Various taxes and tax preferences also influence the use of fossil fuels and, consequently, emissions of carbon dioxide. Tax preferences that may discourage the use of fossil fuel include credits, exclusions, and exemptions to encourage energy conservation, the development of alternative fuel supplies or energy-producing technologies, or both. Excise taxes on fossil fuels and activities related to transportation and travel exert a direct effect on energy use by applying upward pressure on prices, which, in turn, reduces demand. The estimated effects on revenues of tax preferences and excise taxes is quite large. But since the effects on climate change are largely incidental to the purposes of the programs and vary greatly by program, the total is not particularly meaningful.

TABLE 1. FEDERAL PROGRAMS DIRECTLY RELATED TO GLOBAL CLIMATE CHANGE OR ASSOCIATED WITH CLIMATE CHANGE (In millions of dollars of budget authority)

	1997	1998	Requested 1999	Change 1998-1999
Spending Programs and Tax Policies Directly Related to Climate Change				
U.S. Global Change Research Program[a]	1,818	1,867	1,864	-3
Climate Change Technology Initiative	744	820	1,292	471
International Programs	206	213	287	74
Total	2,768	2,901	3,442	542
Revenue Effects of CCTI Tax Incentives[b]	n.a.	n.a.	-478	
Spending Programs Associated with Climate Change				
Partnership for a New Generation of Vehicles (Non-CCTI)[c]	99	82	78	-4
Congestion Mitigation and Air Quality Improvement Program	807	1,257	1,260	3
Advanced Transportation Technologies Consortium (Non-CCTI)[c]	16	16	10	-7
Other Transportation Programs	14	14	5	-9
Energy Conservation Assistance Grant Programs	150	155	191	36
Civilian Nuclear Energy R&D				
Fission (Non-CCTI)[c]	41	7	34	27
Fusion	230	230	228	-1
Total	1,357	1,762	1,806	45
All Programs and Tax Policies				
Total	4,125	4,663	5,248	587

SOURCE: Congressional Budget Office based on information from the Office of Management and Budget; *Budget of the United States Government, Fiscal Year 1999*: U.S. House of Representatives, *Making Appropriations for Energy and Water Development for the Fiscal Year Ending September 30, 1998*, conference report to accompany H.R. 2203, Report 105-271 (September 26, 1997); Department of Energy, *Fiscal Year 1999 Budget Request to Congress: Control Table by Appropriation* (January 30, 1998); Department of Energy, *Fiscal Year 1999 Congressional Budget Request: Science, Technology and Energy for the Future* (February 1998); Department of Housing and Urban Development; Department of the Treasury; Global Environment Facility Secretariat's Office; Department of State; Environmental Protection Agency; and the Agency for International Development.

NOTE: CCTI = Climate Change Technology Initiative; R&D = research and development; n.a. = not available.

a. Totals are augmented in 1997 by $1 million and in 1998 by $1.6 million—funding for the Department of Energy's research on carbon sequestration. Comparable funding for CCTI is $743 million in 1997 and $819 million in 1998.

b. Estimates of revenue losses that would result from enactment of CCTI tax incentives.

c. Funding for activities in this program that are not included in CCTI in the President's 1999 budget.

CURRENT PROGRAMS AND TAX POLICIES AND THE EMISSION OF GREENHOUSE GASES

The federal government is now spending nearly $5 billion annually on programs that are either directly related to climate change or associated with climate change through their effects on the use of fossil fuels. In addition, taxes and tax policies that affect the prices, production, or use of fossil fuels can also affect carbon emissions. The directly related programs are helping U.S. researchers and policymakers learn more about climate change, conduct applied technology research and development to improve energy efficiency, promote international actions, and, to a modest extent, cut emissions of greenhouse gases.

Other programs and tax policies that affect the use of fossil fuels may also indirectly affect emissions of carbon dioxide. A Congressional Budget Office (CBO) study prepared in 1990 looked specifically at carbon dioxide emissions and concluded that whether programs and tax policies then in place had a net positive or negative effect on total emissions was unclear. The studies predicted that, whatever the direction of the effect, it would probably be small.[2] That conclusion still holds. More programs are now designated as climate change programs than in the past. Since most of the funds are spent to learn more about the phenomenon and to improve energy efficiency in the future, the short-term effect is minimal.

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2 Congressional Budget Office, *Energy Use and Emissions of Carbon Dioxide: Federal Spending and Credit Programs and Tax Policies* (December 1990).

CHAPTER II
CURRENT AND PROPOSED SPENDING PROGRAMS AND TAX POLICIES DIRECTLY LINKED TO CLIMATE CHANGE

Current U.S. policy toward climate change focuses on three areas: scientific research and monitoring to better understand climate change, its implications, and what to do about it; applied technology research and development to reduce energy use or to make future limits on carbon emissions less costly to the economy; and activities to promote international agreements and actions.

Two other categories of climate change activities receive less attention now but could dominate federal action in the future. First are efforts to reduce the emissions of greenhouse gases. Several voluntary federal programs to cut emissions exist, but they fall short of meeting any significant reduction goals such as those in the Kyoto Protocol. Second are activities to adapt to the effects of climate change. Adapting to change, instead of trying to prevent it, requires little current action.

SPENDING PROGRAMS DIRECTLY LINKED TO CLIMATE CHANGE

The U.S. Global Change Research Program, the Climate Change Technology Initiative (CCTI), and a group of international activities are the major federal efforts directly linked to climate change. The USGCRP has been in place since 1989. The CCTI, a new umbrella designation, includes programs formerly in the Climate Change Action Plan and the research and development programs of the Department of Energy (DOE).

The U.S. Global Change Research Program

The U.S. Global Change Research Program is a comprehensive effort to understand the science and consequences of a full range of natural and human-induced changes in the Earth's environment. The four main areas of study are seasonal to interannual climate variability; climatic changes over time; changes in ozone, ultraviolet radiation, and atmospheric chemistry; and changes in land cover and ecosystems. Ten executive departments or agencies conduct or fund that research. Funding for 1998 is almost $1.9 billion, and the request for 1999 is nearly the same (see Table 2).[1]

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1. Several Department of Defense (DoD) research activities, totaling $6.5 million in 1998 (the request for 1999 is $6.7 million), also support the programs, but funding for DoD programs is not included in the official totals of the USGCRP.

TABLE 2. FUNDING FOR THE U.S. GLOBAL CHANGE RESEARCH PROGRAM
(In millions of dollars of budget authority)

	1997	1998	Requested 1999	Change, 1998-1999
National Aeronautics and Space Administration	1,369	1,417	1,372	-45
National Science Foundation	166	167	187	20
Department of Energy	109	108	113	5
Department of Commerce	62	62	71	9
Department of Agriculture	57	58	59	1
Department of the Interior	29	29	29	0
Environmental Protection Agency	14	15	21	6
Smithsonian	7	7	7	0
Department of Health and Human Services	4	4	5	1
Tennessee Valley Authority	1	a	a	n.a.
Total	1,818	1,867	1,864	-3

SOURCE: Congressional Budget Office based on information from the Office of Management and Budget; *Budget of the United States Government, Fiscal Year 1999* (February 1998); and National Science and Technology Council, Committee on Environment and Natural Resources, Subcommittee on Global Change Research, *Our Changing Planet, The FY 1999 U.S. Global Change Research Program* (March 1998).

NOTE: n.a. = not applicable.

a. No funding in that year.

About 40 percent of USGCRP funds go to research scientists studying a broad range of questions. The USGCRP publishes an annual report on research objectives and projects, including information on budgetary resources allocated to projects within agencies or departments.[2]

The remaining 60 percent of funding supports development of a space-based observation system—a series of satellites and data systems to monitor the Earth's natural systems. The National Aeronautics and Space Administration controls that activity, which accounts for about 80 percent of NASA's funding within the USGCRP—the remainder being scientific research. Most of those hardware development funds are for the Earth Observing System (EOS) program. The first satellite in that program, the EOS AM-1, is scheduled for launch this year to gather various data on land surface, atmosphere, and oceans.

2. National Science and Technology Council, Committee on Environment and Natural Resources, Subcommittee on Global Change Research, *Our Changing Planet, The FY 1999 U.S. Global Change Research Program* (March 1998).

The Climate Change Technology Initiative

The Climate Change Technology Initiative is a group of programs that would receive increased funding for research, development, and deployment of technologies to improve energy efficiency and reduce carbon emissions. The 1999 budget request totals $1,292 million, an increase of $471 million over the 1998 level (see Table 3). About $100 million of the $471 million would be for new activities. The remainder represents increased funding for existing programs, with some of those being major expansions. The increase over five years from current levels would total $2.7 billion. The CCTI also includes tax incentives, described below.

The CCTI is led by the Department of Energy and the Environmental Protection Agency (EPA). Those two agencies would receive 98 percent of the requested funding for 1999. The remaining 2 percent would fund activities at the Department of Housing and Urban Development, the Department of Commerce's National Institute of Standards and Technology (NIST), and the Department of Agriculture.

Most CCTI programs also serve other policy goals—for example, enhancing energy security, promoting energy efficiency, and improving air quality. The CCTI consists of the following activities within the Department of Energy:

- Energy efficiency and conservation activities, including research and development programs, the Federal Energy Management Program, DOE's contribution to the Partnership for a New Generation of Vehicles (a multiagency program to promote high-efficiency vehicles), municipal energy management, and DOE's contribution to the Advanced Transportation Technologies Consortium, which promotes research on electric and hybrid vehicles. The 1999 request is $617 million, exceeding 1998 funding by $161 million.

- Solar and renewable energy R&D. The 1999 request is $372 million, an increase of $100 million over 1998 levels.

- New activities within the fossil energy research and development program. The President requested $10 million to investigate the sequestration of carbon and $20 million for a new effort to improve the efficiency of the combustion of coal.

- Other research and development. New programs include $10 million to investigate ways to increase the useful life of existing nuclear plants and $27 million in the basic science account for research, principally on carbon sequestration. The research on carbon sequestration in the basic science program and the fossil fuel R&D

TABLE 3. FUNDING FOR PROGRAMS IN THE CLIMATE CHANGE TECHNOLOGY INITIATIVE (In millions of dollars of budget authority)

	1997	1998	Requested 1999	Change, 1998-1999
Department of Energy				
Energy conservation R&D				
Energy efficiency and conservation	273	307	403	
Federal Energy Management Program	20	20	34	
Partnership for a New Generation of Vehicles	120	128	164	
Municipal energy management	2	2	7	
Advanced Transportation Technologies Consortium	a	a	10	
Subtotal	414	457	617	161
Solar and renewable energy R&D[b]	244	272	372	100
Fossil energy R&D				
Sequestration of carbon[c]	1	2	10	
Advanced combustion of coal	a	a	20	
Subtotal	1	2	30	28
Other energy R&D				
Extending life of nuclear plants	a	a	10	
Tracking CO_2 emissions	a	a	3	
Basic science/technology (Sequestration of carbon)	a	a	27	
Subtotal	a	a	40	40
Total	658	730	1,059	329
Environmental Protection Agency[d]				
Former Programs of the Climate Change Action Plan (excluding PNGV)	71	73	115	
Partnership for a New Generation of Vehicles	15	17	35	
Other	a	a	55	
Subtotal	86	90	205	115
Department of Housing and Urban Development (PATH)[e]	a	a	10	10
Department of Commerce (NIST)	a	a	7	7
Department of Agriculture[e]	a	a	10	10
Total	744	820	1,292	471

TABLE 3. CONTINUED

SOURCE: Congressional Budget Office based on information from the Office of Management and Budget; *Budget of the United States Government, Fiscal Year 1999;* U.S. House of Representatives, *Making Appropriations for Energy and Water Development for the Fiscal Year Ending September 30, 1998*, conference report to accompany H.R. 2203, Report 105-271 (September 26, 1997); Department of Energy, *Fiscal Year 1999 Budget Request to Congress: Control Table by Appropriation* (January 30, 1998); Department of Energy, *Fiscal Year 1999 Congressional Budget Request: Science, Technology and Energy for the Future* (February 1998); Department of Housing and Urban Development; Department of the Treasury; Global Environment Facility Secretariat's Office; Department of State; Environmental Protection Agency; and the Agency for International Development.

NOTE: R&D = research and development; PNGV = Partnership for a New Generation of Vehicles; PATH = Partnership for Advancing Technologies in Housing; NIST = National Institute of Standards and Technology

a. No funding in that year

b. Net of prior-year balances, including balance carryovers for Renewable Energy Research Program (research in photovoltaics, biomass/biofuels, wind, hydrogen, and solar photoconversion) in 1998 and 1999.

c. Climate Change Technology Initiative (CCTI) totals in the table are augmented in 1997 by $1 million and in 1998 by $1.6 million—funding for the Department of Energy's carbon sequestration research. Comparable funding for CCTI is $743 million in 1997 and $819 million in 1998.

d. Figures for the Environmental Protection Agency in 1997 and 1998 equal agency funding for Climate Change Action Plan (CCAP) programs.

e. Some funding related to climate change activities for Department of Housing and Urban Development (HUD) and Department of Agriculture (USDA) were not included in order to be consistent with the President's budget request. HUD used about $1 million in "seed" funds for the Partnership for Advancing Technologies in Housing program in 1998; those funds were taken from HUD's general R&D fund and used as start-up funds for the program. Funding for Climate Change Action Plan (CCAP) programs at USDA was $8 million in 1997 and 1998. CBO was unable to determine what happened to the USDA CCAP programs.

programs is the only example of newly proposed research that would not also serve other energy policy goals.

CCTI activities within the Environmental Protection Agency would include the bulk of programs that were formerly part of the Climate Change Action Plan (CCAP). Many of the CCAP programs administered by EPA would be expanded under the proposal, including the Energy Star Programs for buildings, appliance labeling, and homes. The 1999 request for the former CCAP activities other than the Partnership for a New Generation of Vehicles (PNGV) is about $115 million, up from $73 million in 1998. The PNGV, formerly part of CCAP, is now part of the Climate Change Technology Initiative. EPA's contribution to PNGV would roughly double, from $17 million to $35 million, in the 1999 request.

The Partnership for a New Generation of Vehicles, launched in 1993, is a cooperative effort between the federal government and industry to foster breakthrough technology in personal vehicles. In addition to DOE and EPA, the Department of Commerce, the National Science Foundation, and the Department of Transportation receive funding for PNGV activities. One goal of the program is to develop a production prototype vehicle capable of 80 miles per gallon by 2004. Funding was about $234 million in 1997 and $227 million in 1998. The President's request for PNGV funding for all agencies, whether included in CCTI or not, is $50 million above 1998 levels.

The CCTI program in the Department of Housing and Urban Development is the Partnership for Advancing Technologies in Housing (PATH). The purpose of PATH is to develop, demonstrate, and help to commercialize safe, energy-efficient housing technologies. The PATH program received about $1 million in seed money from a HUD R&D account in 1998. The program would be funded at $10 million in 1999 under the President's proposal.

CCTI programs at the Department of Agriculture (USDA) would fund research on biomass and carbon sequestration. CCTI would allot $10 million to USDA to support research on the conversion of wood, crop wastes, and energy crops to fuels and electricity and on enhancing the carbon-sequestering capabilities of agricultural species.

The CCTI also includes funding for new research at the National Institute of Standards and Technology in the Department of Commerce. Research efforts at NIST would work to improve measurements of greenhouse gases and would support biotechnology work on plant metabolism and carbon sequestration. The proposed level of funding for NIST programs in 1999 is $7 million.

International Activities That Target Climate Change

The United States contributes to various international efforts to assess the problem of climate change and to reduce emissions of carbon dioxide and other greenhouse gases. Contributions to the Intergovernmental Panel on Climate Change, the Global Environment Facility, the Montreal Protocol, and bilateral assistance programs totaled more than $200 million in 1998 (see Table 4).

Intergovernmental Panel on Climate Change and the Climate Change Secretariat. The Intergovernmental Panel on Climate Change (IPCC) was established in 1988 by the World Meteorological Organization and the United Nations Environment Programme (UNEP) to assess the available scientific, technical, and socioeconomic information in the field of climate change. The IPCC released its Second Assessment Report in 1995 and periodically produces technical papers and develops methodologies (for example, inventories of greenhouse gases) for use by the parties to the Climate Change Convention. The Climate Change Secretariat was organized under the U.N. Framework Convention on Climate Change to handle coordination and administrative responsibilities under the Convention. The United States contributed $5 million to the IPCC and the Climate Change Secretariat in 1998. The 1999 request is $8 million.

TABLE 4. FUNDING FOR INTERNATIONAL PROGRAMS DIRECTLY RELATED TO GLOBAL CHANGE (In millions of dollars of budget authority)

	1997	1998	Requested 1999	Change, 1998-1999
Department of State				
Intergovernmental Panel on Climate Change and the Climate Change Secretariat[a]	3	5	8	3
Bilateral Assistance Grant Program (AID)	150	150	150	0
Department of the Treasury				
Global Environment Facility[b]	13	18	73	55
Montreal Protocol				
Department of State	28	28	34	
Environmental Protection Agency	12	12	21	
Total	40	40	55	15
All Programs				
Total	206	213	287	74

SOURCE: Congressional Budget Office based on information from the Office of Management and Budget; *Budget of the United States Government, Fiscal Year 1999*; Department of the Treasury; Global Environment Facility Secretariat's Office; Department of State; Environmental Protection Agency; and the Agency for International Development.

NOTE: AID = Agency for International Development.

a. Funding data are voluntary contributions to the Climate Stabilization Fund.

b. Funding for the "climate" share of the Global Environment Facility was calculated as 38 percent of the total budget auhority (net of funding for payments in arrears).

Bilateral Assistance. Bilateral assistance is primarily conducted through the U.S. Agency for International Development (AID). AID has made the mitigation of climate change one of two global environmental priorities. The agency supports grants focusing on this issue to nine key countries—India, Indonesia, the Philippines, Mexico, Brazil, Russia, Ukraine, Kazakstan, and Poland—and supports a broader portfolio of energy efficiency, renewable energy, and forestry activities related to climate change. Obligations for grants related to climate change were $150 million in 1998, the same as the request for 1999.

Global Environment Facility. The Global Environment Facility (GEF) is an international financial institution established in 1991 to provide developing countries with grants and low-interest loans for projects in four areas: global climate change, international waters, biological diversity, and depletion of the ozone layer. The GEF is run jointly by the United Nations Development Programme (UNDP), UNEP, and the World Bank. Budget authority for climate change activities was about $18 million in 1998 (38 percent of all funds appropriated for the GEF). The total request for funds for the GEF in 1999 is $300 million—38 percent of which is $114 million. The 1999 budget identifies about $41 million (of the $114 million) as "payments in arrears," leaving $73 million that may be available for new obligation.

Montreal Protocol. The Montreal Protocol is an international environmental agreement with the objective of eliminating the use of substances that deplete the ozone layer in the stratosphere and are believed to contribute to climate change: chlorofluorocarbons, halons, and hydrochlorofluorocarbons. The agreement is implemented by the World Bank, UNDP, UNEP, and the United Nations Industrial Development Organization. The U.S. contribution, which is jointly paid by the Department of State and the Environmental Protection Agency, totaled $40 million in 1998. CBO includes spending for the Montreal Protocol in this memorandum because of the close link between ozone-depleting gases and greenhouse gases.

The request for 1999 is $55 million—$34 million for the Department of State and $21 million for the Environmental Protection Agency.

TAX PROPOSALS DIRECTLY LINKED TO CLIMATE CHANGE

As part of its Climate Change Technology Initiative, the Administration has proposed several tax preferences designed to encourage the development of new technologies that offer superior energy efficiency and to induce purchases of higher-cost, energy-efficient equipment. Improving energy efficiency would reduce emissions of carbon dioxide, the cost of complying with any future limits on emissions, or both.

The Administration sought to tailor the incentives to technologies that either are currently available or will be when the credits go into effect and to equipment that can be precisely defined for purposes of the Internal Revenue Service. According to estimates of the Joint Committee on Taxation (JCT), the tax incentives would result in revenue losses of $3.8 billion through 2003 and $9.8 billion through 2008 (see Table 5).[3]

3. Joint Committee on Taxation, "Estimated Budget Effects of the Revenue Provisions Contained in the President's Fiscal Year 1999 Budget Proposal," February 24, 1998.

TABLE 5. ESTIMATES OF REVENUE LOSSES FROM PROPOSALS FOR ENERGY AND ENVIRONMENTAL TAX INCENTIVES IN THE ADMINISTRATION'S 1999 BUDGET (In millions of dollars)

Proposal	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	1998-2003	1998-2008
Tax Credits													
Fuel-Efficient Vehicles	0	0	a	-89	-299	-544	-904	-1,011	-1,004	-994	-979	-931	-5,823
Energy-Efficient Building Equipment	0	-125	-225	-285	-340	-410	-155	-20	-5	1[b]	1[b]	-1,385	-1,563
CHP Equipment	18[c]	-326	-285	-90	-116	-115	-39	2[b]	3[b]	4[b]	4[b]	-913	-938
Wind and Biomass	0	-2	-7	-21	-43	-71	-109	-128	-131	-134	-137	-144	-784
Energy-Efficient Homes	0	-5	-25	-40	-55	-75	-35	0	0	0	0	-200	-235
Circuit Breaker Equipment	0	-5	-10	-15	-10	-5	-2	2[b]	1[b]	1[b]	1[b]	-45	-42
Rooftop Solar Equipment	0	-2	-6	-9	-12	-16	-18	-26	-12	d	d	-43	-100
PFC and HFC Recycling Equipment	0	-5	-10	-10	-5	-3	1[b]	1[b]	1[b]	1[b]	d	-33	-29
Other Tax Incentives													
Parking and Transit Benefits	0	-8	-16	-25	-31	-35	-36	-39	-43	-42	-44	-114	-318
All Tax Incentives													
Total	18	-478	-584	-584	-911	-1,274	-1,297	-1,219	-1,190	-1,163	-1,154	-3,808	-9,832

SOURCE: Congressional Budget Office based on the Joint Committee on Taxation's estimates of the revenue effects of the Climate Change Technology Initiative in the President's 1999 budget.

NOTE. CHP = combined heat and power; PFC = perfluorocompound, HFC = hydrofluorocarbon.

a Revenue loss of less than $500,000

b Positive revenue estimates reflect projected lower deductions for depreciation

c. The positive revenue estimate reflects a projected slowdown in investment pending enactment of the credit, which in turn would result in lower deductions for depreciation

d Revenue gain of less than $500,000

Tax Credits

Most of the proposals for tax preferences are for new or expanded tax credits.

Tax Credits for Highly Fuel-Efficient Vehicles. Under current law, a 10 percent credit is available for the purchase of new electric vehicles for use by the taxpayer and not for resale. In addition, a deduction is available for qualified clean-fuel vehicles. The proposed tax credits are intended to reduce carbon dioxide emissions by encouraging the manufacture and purchase of fuel-efficient vehicles. The proposal is for two temporary tax credits: a $4,000 credit for each vehicle that has three times the base fuel economy for its class, and a $3,000 tax credit for each vehicle that has twice the base fuel economy for its class. The $4,000 credit would be available in calendar years 2003 through 2006 and would subsequently be reduced by $1,000 a year, phasing out completely in 2010. The $3,000 credit would be available for calendar years 2000 through 2003 and would phase out in 2006, also at the rate of $1,000 a year. The credits would be available for cars, sport utility vehicles, minivans, light trucks as well as hybrid, electric, and other light vehicles. Taxpayers who claimed the new credits would not be able to claim the credit that is currently available for electric vehicles or the deduction for clean-fuel vehicles.

The JCT estimates that enacting the proposal would reduce revenues by $931 million from 1998 through 2003 and by $5,823 million from 1998 through 2008.

Tax Credit for Energy-Efficient Building Equipment. The proposal would provide a credit for the purchase of certain types of energy-efficient building equipment: fuel cells, electric heat pumps and advanced natural gas water heaters, advanced natural gas and residential-size electric heat pumps, and advanced central air conditioners. The credit, which would be nonrefundable, would be equal to 20 percent of the purchase price, subject to a cap. For businesses, it would be subject to the limits on the general business credit, and it would reduce the basis of the equipment. The credit would be in effect from January 1, 2000, to December 31, 2004, for fuel cells, and from January 1, 1999, to December 31, 2003, for other types of equipment. To be eligible for the credit, the equipment would have to meet specified criteria.

The JCT estimates that the proposal would result in revenue losses of $1,385 million between 1998 and 2003 and $1,563 million between 1998 and 2008.

Investment Tax Credit for Combined Heat and Power Systems. Combined heat and power (CHP) systems are used to produce electricity and process heat or mechanical power from a single primary energy source. The systems use thermal energy that is otherwise wasted in the process of producing electricity conventionally—which, in turn, results in less consumption of fossil fuels, reduced carbon emissions, and lower costs. The proposal is for a 10 percent investment tax credit for CHP systems with electrical capacity of more than 50 kilowatts. Investments in the systems with cost-recovery periods of less than 15 years would be eligible for the credit only if a 15-

year recovery period and the 150 percent declining-balance method were used to calculate depreciation deductions.

The systems would be required to produce at least 20 percent of their useful energy in the form of both thermal energy and electric or mechanical power. To qualify for the credit, CHP systems would have to meet specified energy-efficiency and percentage-of-energy tests, as certified by qualified engineers, pursuant to regulations issued by the Secretary of the Treasury. The credit would be subject to the limits on general business credits and would be available for equipment placed in service during calendar years 1999 through 2003.

The JCT estimates that the proposal would result in revenue losses of $913 million through 2003.

Wind and Biomass Tax Credit. A tax credit of 1.5 cents per kilowatt hour (indexed for inflation after 1992) is currently available for electricity produced from wind or biomass. It now applies only to facilities placed in service before June 1, 1999, for wind and before July 1, 1999, for biomass. The proposal would extend the credit for both types of facilities placed in service by July 1, 2004. Unlike the other proposed tax credits, the wind and biomass credit is based on production rather than investment. The electricity must be sold to an unrelated third party, and the credit is limited to the first 10 years of production.

The JCT estimates the potential revenue losses of the proposal at $144 million through 2003 and $784 million through 2008.

Tax Credit for Purchase of New Energy-Efficient Homes. The proposal would provide a tax credit of 1 percent of the purchase price up to $2,000 to buyers of new homes that use at least 50 percent less energy for heating, cooling, and hot water than the Model Energy Code standard for single-family homes. The credit would be available for calendar years 1999 through 2003. Homes purchased in 2004 and 2005 would be eligible for a maximum credit of $1,000.

The JCT estimates that the proposal would result in revenue losses of $200 million between 1998 and 2003 and an additional $35 million in 2004.

Tax Credit for Replacement of Circuit Breaker Equipment. The proposal would provide a 10 percent tax credit to replace circuit breakers installed before 1986 that use sulfur hexafluoride (SF_6), a potent greenhouse gas. The replaced circuit breakers must be destroyed to prevent further use. The credit applies to property placed in service in calendar years 1999 through 2003 and is subject to the limits of the general business credit. Also, the amount of credit claimed reduces the depreciable basis of qualified property for which the credit is taken.

The JCT estimates that the proposal would result in revenue losses of $45 million between 1998 and 2003.

Tax Credit for Rooftop Solar Equipment. The proposed tax credit would be available for two types of solar equipment—photovoltaic heating systems and water heating systems located on or adjacent to buildings. The credit would be equal to 15 percent of the total investment in either system up to a maximum credit of $2,000 for rooftop photovoltaic heating systems and $1,000 for solar water heating systems. It would be nonrefundable and would not be available for systems to heat swimming pools. For businesses, the credit would reduce the depreciable basis of the property by the amount claimed and would be subject to the limits of the general business credit. It would apply to equipment placed in service during calendar years 1999 through 2003 for solar water heating systems and through 2005 for rooftop photovoltaic systems.

Under current law, a 10 percent energy investment tax credit for businesses is available for equipment that uses solar energy to generate electricity, to heat or cool or provide hot water for use in a structure, or to provide solar-process heat. The equivalent credit for residential solar systems expired in 1985. Under the proposals, businesses would have to choose between the present and the proposed tax credits.

The JCT estimates that enacting the proposal would reduce revenues by $43 million through 2003 and $100 million through 2008.

Tax Credit for Perfluorocompound and Hydrofluorocarbon Recycling Equipment. Perfluorocompounds (PFCs) and certain hydrofluorocarbons (HFCs) are extremely potent greenhouse gases because of their stability in the atmosphere and their capacity to absorb radiation. Under current law, manufacturers who install equipment to recover or recycle PFC and HFC gases used in producing semiconductors may depreciate the cost of that equipment over six years. The proposal would make available a 10 percent tax credit for installing PFC and HFC recovery or recycling equipment. The credit would be subject to the limits of the general business tax credit and would reduce the depreciable basis of the equipment by the amount claimed. To qualify, the equipment must recover at least 99 percent of the PFCs and HFCs used and must be placed in service between January 1, 1999, and December 31, 2003.

The JCT estimates that enacting the proposal would reduce revenues by about $33 million between 1998 and 2003.

Parking and Transit Benefits

The Administration has also proposed an increase in benefits to encourage the use of mass transit and van pools. Current law provides for the exclusion of parking benefits from gross income, regardless of whether the benefits are in addition to or in lieu of other employee compensation. However, for transit and van-pool benefits, the exclusion applies only if those benefits are in addition to other compensation. The current limits on the income exclusion (in 1993 dollars) are $155 per month for parking and $60 for transit passes and van-pool benefits. The proposal calls for eliminating the relative tax advantage of parking benefits. It would treat parking, transit passes, and van-pool benefits in the same way, subject to the same limits that currently apply to parking.

The JCT estimates that the proposal would reduce revenues by $114 million through 2003 and $318 million through 2008.

CHAPTER III
OTHER FEDERAL SPENDING PROGRAMS AND TAX POLICIES ASSOCIATED WITH CLIMATE CHANGE

Other federal programs and tax policies affect energy use and emissions of carbon dioxide—some positively, some negatively. Energy use is so important to the economy, and the government affects economic activity in so many ways, that a very broad range of government programs could be included. Deciding where to draw the line is difficult. The programs and tax policies included in this chapter represent one way to inventory a set of programs and tax policies associated with energy use and climate change.

Programs closely associated with climate change include activities in transportation, energy conservation, and nuclear energy research and development that could affect emissions of carbon dioxide (or lower the costs of using less carbon). Those programs have multiple objectives—as do many that are directly related to climate change. Isolating the portions of the programs that should be charged to climate change is impossible. Nevertheless, since those programs are linked to activities related to climate change, they may be part of future changes to the policy mix.

FEDERAL SPENDING PROGRAMS THAT AFFECT ENERGY USE

The federal government currently funds several programs that have the purpose or effect of conserving energy or reducing emissions of greenhouse gases but that are not identified as being directly linked to climate change (see Table 6). The 1999 budget requests for most of those programs are near 1998 levels, with the exception of the Department of Energy's Weatherization Assistance Program, which would increase from $125 million to $154 million, and civilian nuclear R&D, which would rise from $7 million to $34 million. Programs and activities included are:

- The non-CCTI activities of the Partnership for a New Generation of Vehicles administered by the Department of Commerce's NIST, the National Science Foundation, and the Department of Transportation (DOT). The 1999 request totals $78 million, which is a slight decrease from 1998 levels.

- The Congestion Mitigation and Air Quality Improvement Program, which would remain at about the same level as in 1998—$1.3 billion.

TABLE 6. FUNDING FOR FEDERAL PROGRAMS ASSOCIATED WITH CLIMATE CHANGE
(In millions of dollars of budget authority)

	1997	1998	Requested 1999	Change, 1998-1999
Partnership for a New Generation of Vehicles (Non-CCTI)				
Department of Commerce	41	25	22	
National Science Foundation	54	53	52	
Department of Transportation	4	4	4	
Subtotal	99	82	78	-4
Congestion Mitigation and Air Quality Improvement Program (CMAQ)[a]				
Department of Transportation, Federal Highway Administration				
Transit	362	563	565	
Traffic flow	265	412	413	
Surface transportation program devoted to CMAQ	57	88	88	
Shared ride	36	55	55	
Demand management	31	48	48	
Bicycle/pedestrian	22	34	34	
Other	36	57	57	
Subtotal	807	1,257	1,260	3
Advanced Transportation Technologies Consortium (Non-CCTI)[b]				
Department of Defense	15	15	c	
Department of Transportation				
Federal Transit Administration	2	2	c	
Research and Special Programs Administration	c	c	10	
Subtotal	16	17	10	-7
Other Transportation Programs				
Department of Transportation, Federal Transit Administration				
Advanced Technology Transit Bus	7	10	1	
Fuel Cell Bus	8	4	4	
Subtotal	14	14	5	-9

TABLE 6. CONTINUED

	1997	1998	Requested 1999	Change, 1998-1999
Energy Conservation Assistance Grant Programs				
DOE, Office of State and Community Programs				
Weatherization Assistance	121	125	154	
State Energy Conservation	29	30	37	
Subtotal	150	155	191	36
Civilian Nuclear Energy Research and Development				
Fission (Non-CCTI)	41	7	34	
Fusion	230	230	230	
Subtotal	271	237	262	26
All Programs				
Total	1,357	1,762	1,806	45

SOURCE: Congressional Budget Office based on information from the Office of Management and Budget; *Budget of the United States Government, Fiscal Year 1999*; House Committee on Appropriations, *Department of Defense Appropriations Bill, 1998*, report to accompany H.R. 2266, Report 105-206, (July 25, 1997); Department of Energy, *Fiscal Year 1999 Congressional Budget Request: Science, Technology and Energy for the Future* (February 1998); Department of Energy, *Fiscal Year 1999 Budget Request to Congress: Control Table by Appropriation* (January 30, 1998); Department of Transportation, Federal Highway Administration and Federal Transit Administration; U.S. House of Representatives, *Making Appropriations for Department of Transportation and Related Agencies for Fiscal Year Ending September 30, 1997*, conference report to accompany H.R. 3675, Report 104-785 (September 16, 1996); U.S. House of Representatives, *Making Appropriations for Department of Transportation and Related Agencies for Fiscal Year Ending September 30, 1998*, conference report to accompany H.R. 2169, Report 105-313 (October 7, 1997); and the Northeast Alternative Vehicle Consortium

NOTE: CCTI = Climate Change Technology Initiative; CMAQ = Congestion Mitigation and Air Quality Improvement Program; DOE = Department of Energy

a. Figures for CMAQ categories were calculated using the percentage share held by each category from 1992 to 1996 as follows: transit, 44.8 percent; traffic flow, 32.8 percent; surface transportation program devoted to CMAQ, 7.0 percent; shared ride, 4 4 percent; demand management, 3.8 percent; bicycle/pedestrian, 2 7 percent; and other, 4.5 percent On May 22, 1998, the House and Senate passed the Transportation Equity Act for the 21st Century. The act would authorize funds to be appropriated out of the Highway Trust Fund for the CMAQ program at a funding level of $1.35 billion in 1999.

b Requested funding for the Advanced Transportation Technologies Consortium for 1999 is $20 million—$10 million for the Department of Energy and $10 million for the Department of Transportation—which is about $3.5 million greater than funding in 1998.

c. No funding in that year

- o The Advanced Transportation Technologies Consortium, which would receive $10 million in funding from the Department of Transportation in addition to the $10 million in funding from DOE under CCTI.

- o The Advanced Technology Transit Bus and Fuel Cell Bus Programs at the Federal Transit Administration, which support the development and market penetration of low-emission, light-weight, low-cost buses. Funding for those programs totaled $14 million in 1998; the total funding request for 1999 is only $5 million because the transit bus program ends next year.

- o Conservation grants administered by the Department of Energy. Those grants would be funded at $191 million in 1999—an increase of $36 million compared with 1998. The additional funding would expand programs that administer block grants to states to fund energy-efficiency programs and weatherization of low-income housing.

- o Civilian nuclear energy R&D (that was not included in the CCTI). Those activities are University Nuclear Science and Reactor Support (at $10 million, an increase of $3 million from 1998), a new $24 million Nuclear Energy Research Initiative, and research on magnetic fusion, funding for which has been stable for several years and comes in at $228 million.

TAX PROVISIONS THAT AFFECT ENERGY USE

Several tax preferences in current law directly or indirectly discourage reliance on fossil fuels. In addition, several excise taxes raise the price of fossil fuels and thereby reduce demand for them.

Tax Preferences to Promote Less Use of Fossil Fuels

Of the tax preferences designed to encourage less reliance on fossil fuels, two account for the largest revenue losses: the excise tax exemption for alcohol fuels, and the exclusion from income of interest on state and local bonds for hydroelectricity-generating facilities and solid waste disposal facilities that produce electricity (see Table 7). These and other preferences are described below.

Income Tax Credits and Excise Tax Exemptions for Alcohol Fuels. The tax code provides three income tax credits for alcohol-based motor fuels: the alcohol mixture

TABLE 7. ESTIMATES OF TAX EXPENDITURES FROM PREFERENCES THAT DISCOURAGE RELIANCE ON FOSSIL FUELS (In millions of dollars)

Tax Preference	1996	1997	1998	1999	2000	2001	2002
Tax Credits for Alcohol Fuels	11	11	11	11	11	11	3
Excise Tax Exemption for Alcohol Fuels	511	520	530	539	547	556	564
Exclusion of Energy Conservation Subsidies Provided by Public Utilities	55	40	35	35	35	40	40
Tax Credits for Investments in Solar and Geothermal Energy Facilities	80	80	75	70	70	70	70
Tax Credit for Electricity Production from Wind and Biomass	5	10	20	35	37	38	40
Deductions for Clean-Fuel Vehicles and Refueling Property	16	10	10	12	13	15	4
Tax Credit for Electric Vehicles	1	11	25	34	54	71	77
Exclusion of Interest on State and Local IDBs for Energy Production Facilities	225	225	215	205	215	215	210

SOURCE: Congressional Budget Office based on the Joint Committee on Taxation's estimates of the revenue effects of the Climate Change Technology Initiative in the President's 1999 budget.

NOTES: Tax expenditures are revenues that the federal government forgoes as a result of provisions in the income tax code that give selective relief to particular groups of taxpayers or special incentives for particular types of economic activity.

IDBs = industrial development bonds.

or blender's credit, the pure alcohol credit, and the credit for small ethanol producers. The first two credits are 53 cents per gallon of ethanol and 60 cents per gallon of methanol of at least 190 proof; for mixtures of between 150 proof and 190 proof, the credits are 40 cents per gallon of alcohol and 45 cents per gallon of methanol. The credit for small ethanol producers is 10 cents per gallon of ethanol produced, used, or sold for use as a transportation fuel. That credit is limited to 15 million gallons of annual alcohol production from firms with a production capacity of less than 30 million gallons. The credits, which were extended under the Transportation Equity Act of 1998, are in effect through December 31, 2007.

Blenders have a choice of using the income tax credit or claiming an excise tax exemption of 5.4 cents for mixtures of ethanol and liquid motor fuels. Because the credits are included in income and apply only to a portion of income tax liability, most blenders opt for the excise tax exemption. Consumption of ethanol motor fuel has increased sharply in the past 20 years. That increase is probably a result not so much of the income tax credits but of the exemption of alcohol fuels from excise taxes. The Transportation Equity Act extended the excise tax reduction through 2007.

The extent to which the use of ethanol motor fuels reduces emissions of greenhouse gases has been the subject of recent reports by the General Accounting Office (GAO) and Argonne National Laboratory (ANL), among others. The GAO reports concluded that the effect on emissions is difficult to determine but is likely to be minimal. By contrast, the ANL study concluded that the use of corn-based ethanol significantly reduces both the use of fossil energy and emissions of greenhouse gases.[1]

Exclusion of Energy Conservation Subsidies Provided by Public Utilities. The tax code permits residential customers to exclude from income the subsidies provided by public utilities for the purchase or installation of an energy conservation item. The exclusion, which is permanent, reduces the costs of programs financed by utilities to conserve energy.

Tax Credit for Investments in Solar and Geothermal Energy Facilities. The tax code provides a 10 percent credit for business investment in solar and geothermal energy equipment (electric utilities do not qualify). The credits are permanent.

Tax Credit for Electricity Production from Wind and Biomass. The tax code permits a 1.5-cent credit (in 1992 dollars, adjusted for inflation) per kilowatt hour for electricity produced from wind energy or "closed-loop" biomass. (Closed-loop

1. See General Accounting Office, *Tax Policy: Effects of the Alcohol Fuel Incentives*, Letter Report, GAO/GGD-97-41 (1997), and *Motor Fuels: Issues Related to Reformulated Gasoline, Oxygenated Fuels, and Biofuels*, Letter Report, GAO/RCED-96-121 (1996); Argonne National Laboratory, *Fuel-Cycle Fossil Energy Use and Greenhouse Gas Emissions of Fuel Ethanol Produced from U.S. Midwest Corn* (Oak Ridge, Tenn.: 1997).

biomass generates electricity using matter from plants grown solely for fuel.) The credit was instituted to encourage development of technologies that use renewable energy resources rather than conventional fossil fuels. The electricity must be produced from a qualified facility and must be sold to an unrelated third party. (A qualified facility is one that is placed in service after 1992 and before July 1, 1999, for biomass and after 1993 and before June 1, 1999, for wind. The facility must be owned by the taxpayer who claims the credit.) The credit is available for 10 years after a facility is placed in service. It is phased out as the price of electricity from the renewable resource rises over a 3-cent range, from 8 cents to 11 cents (in 1992 dollars, adjusted for inflation). It is also reduced by other government subsidies, including tax-exempt financing. The Administration is proposing to extend the credit.

Deductions for Clean-Fuel Vehicles and Refueling Property and the Tax Credit for Electric Vehicles. Deductions are available for the portion of the cost attributed to the engine, the fuel delivery system, and the exhaust system of vehicles that burn clean fuel. The vehicle must be new, but deductions can also be taken for retrofitting vehicles propelled by gasoline or diesel fuel. Costs are limited by a vehicle's type and weight. The deductions phase out between 2002 and 2005.

Electric vehicles qualify for a tax credit but not the deduction. The credit is 10 percent of the cost of the vehicle up to $4,000. It, too, phases out between 2002 and 2005. The tax preferences are intended to make clean-fuel and electric vehicles more economically attractive, but costs are still high relative to conventional vehicles.

Exclusion of Interest on State and Local Industrial Development Bonds for Energy Production Facilities. Tax-exempt financing is limited to solid waste disposal facilities that produce electric energy and to the construction of hydroelectric generating facilities at dam sites built before 1979 or at sites without dams that require no impoundment of water. The bonds generally are subject to a state-by-state annual volume cap on private activity bonds; however, bonds issued for governmentally owned solid waste disposal facilities are not subject to the cap. The exclusion is permanent.

Excise Taxes and Fees

Excises and fees that may result in decreased emissions of carbon dioxide chiefly include taxes on coal, motor fuels, equipment, and transactions related to travel and shipping (see Table 8). Those tax receipts primarily finance spending on roads, airports, harbors, and other transportation needs. Financing those transportation programs could increase emissions of carbon dioxide. Building more and better roads, airports, and harbors may provide an incentive for more travel. Taxes on motor fuels are dedicated to several trust funds. The largest share of revenue goes

TABLE 8. ESTIMATES OF RECEIPTS FROM EXCISE TAXES AND FEES THAT MAY REDUCE THE USE OF FOSSIL FUELS (In millions of dollars)

Tax or Fee	1996	1997	1998	1999	2000	2001	2002
Highway Trust Fund[a]							
Trust Fund Taxes	23,456	24,354	25,569	37,873	32,499	33,010	33,548
General Fund Taxes	6,513	6,772	321	489	414	420	426
Total	29,968	31,126	25,890	38,362	32,913	33,430	33,974
Airport and Airway Trust Fund[a]							
Trust Fund Fuel Taxes	688	753	798	836	867	893	918
Other Trust Fund Taxes	1,153	3,822	7,566	9,254	8,446	8,923	9,643
General Fund Taxes	584	612	0	0	0	0	0
Total	2,425	5,187	8,364	10,090	9,313	9,816	10,561
Aquatic Resources Trust Fund							
Taxes on Motorboat Fuels, Motors, and Sportfishing Equipment	315	321	281	376	336	339	345
Inland Waterways Trust Fund							
Fuel Taxes	103	107	110	113	115	117	119
Land and Water Conservation Trust Fund							
Taxes	1	1	1	1	1	1	1
Leaking Underground Storage Tank Trust Fund							
Fuel Taxes	40	0	139	206	176	179	181
Harbor Maintenance Trust Fund							
Cargo Taxes	746	784	826	873	922	972	1,025
Hazardous Substance Superfund							
Petroleum, Chemicals, and Feedstock	211	0	0	0	0	0	0
Black Lung Disability Trust Fund							
Coal Tax	615	632	641	651	661	671	681

(Continued)

TABLE 8. CONTINUED

Tax or Fee	1996	1997	1998	1999	2000	2001	2002
Abandoned Mine Reclamation Fund							
Coal Fee	256	266	262	260	262	267	274
Taxes Not Dedicated to Trust or Special Funds							
Gas Guzzler Taxes	33	47	37	34	34	34	34
Ozone-Depleting Chemicals Taxes	429	100	65	14	0	0	0

SOURCE: Congressional Budget Office.

a. Projections reflect modifications in the rules governing deposits. Taxes imposed on gasoline, diesel fuel, special motor fuels, and kerosene that would otherwise be deposited with the Treasury after July 31, 1998, and before September 20, 1998, are not required to be deposited until October 5, 1998. The same rule modifications apply to air cargo taxes. In addition, deposits of air passenger taxes normally due after August 14, 1998, and before October 1, 1998, are now due on October 5, 1998.

to transportation, with smaller amounts going to nature conservation and environmental cleanup. The Land and Water Conservation Trust Fund accumulates roughly $1 million per year from oil and gas leases. The only excise taxes not dedicated to trust or special funds and designed solely to discourage consumption of products that are detrimental to the environment (as opposed to paying for cleanup after damage has occurred) are taxes on cars that do not achieve specified fuel economy ratings and on ozone-depleting chemicals. Those taxes raise nominal amounts of revenue compared with the trust fund taxes.

Highway Trust Fund. Several excise taxes finance the Highway Trust Fund, which was established under the Federal-Aid Highway Act of 1956. The primary sources of revenue are a tax of 18.3 cents per gallon levied on gasoline, a tax of 24.3 cents per gallon on diesel fuel, and taxes on gasohol and other special fuels. Other trust fund taxes are levied on sales of tires, inner tubes, trucks, tractors, and trailers. In addition, annual use taxes are levied on trucks weighing more than 55,000 pounds. Of the total taxes on gasoline, 1.5 cents per gallon is dedicated to a special mass transit account, which may be used for capital and related expenditures. The taxes dedicated to the Highway Trust Fund were scheduled to expire on September 30, 1999, with the exception of a motor fuels excise tax of 4.3 cents per gallon. The Transportation Equity Act of 1998 extended them through 2005.

Airport and Airway Trust Fund. Taxes on air passenger tickets, air cargo, noncommercial jet fuel and aviation gasoline, domestic flight segments, and international departures and arrivals are dedicated to the Airport and Airway Trust Fund. Those taxes were scheduled to expire on September 30, 1997. The Taxpayer Relief Act of 1997 extended them with significant modifications, including new taxes on domestic flight segments and international arrivals. The trust fund, which was established in the Airport and Airway Development and Revenue Acts of 1970, finances a substantial portion of the Federal Aviation Administration's budget. When fully phased in, the domestic air passenger tax will be 7.5 percent of the transportation cost plus $3 per flight segment (indexed for inflation). Air cargo is subject to a 6.25 percent excise tax. Aviation gasoline is subject to a permanent excise tax of 4.3 cents per gallon. (Noncommercial aviation fuels are subject to an excise tax of 15 cents per gallon on aviation gasoline and 17.5 cents per gallon on jet fuel.) Commercial air passengers coming from another country or leaving the United States are subject to a $12 tax per arrival or departure.

Aquatic Resources Trust Fund. Taxes on gasoline, electric outboard motors, sportfishing equipment, and sonar devices for finding fish are dedicated to the Aquatic Resources Trust Fund, which was established under the Deficit Reduction Act of 1984. The trust fund is composed of two accounts: one for fish management and restoration and the other for boating safety. Taxes on diesel fuel for recreational motorboats were repealed by the Taxpayer Relief Act of 1997.

Inland Waterways Trust Fund. Taxes dedicated to the Inland Waterways Trust Fund are levied at the rate of 20 cents a gallon on fuels used by commercial vessels plying specified inland and intracoastal waterways. The expenditures from the trust fund, which was established in 1978 under the Inland Waterways Revenue Act, finance up to half of the construction and rehabilitation expenditures for navigation projects on a designated system of 27 inland and intracoastal waterways.

Leaking Underground Storage Tank Trust Fund. An additional 0.1-cent tax on gasoline, diesel, and other motor fuels; aviation fuels; and fuels used by vessels in inland waterways is dedicated to the Leaking Underground Storage Tank Trust Fund. Expenditures from the trust fund finance the cleanup of underground petroleum tanks that are leaking. The tax, which was initially established under the Superfund Amendments and Reauthorization Act of 1986 and had expired at the end of 1995, was reinstated by the Taxpayer Relief Act of 1997.

Harbor Maintenance Trust Fund. Under the Water Resources Development Act of 1986, a tax on both ship passengers and the value of cargo loaded or unloaded at U.S. harbors, channels, and ports was dedicated to the operation and maintenance costs of the Saint Lawrence Seaway and harbors within the United States. The tax is 0.125 percent and, in the case of passengers, had been levied on transportation charges. The Supreme Court recently held that the harbor maintenance tax was unconstitutional as applied to exports. Subsequently—in June 1998—the U.S. Court of International Trade ruled that the tax on embarking passengers was also unconstitutional.

Black Lung Disability Trust Fund. Taxes of $0.55 a ton on surface-mined coal and $1.10 a ton on underground-mined coal other than lignite are dedicated to the Black Lung Disability Trust Fund, established in 1977 under the Black Lung Benefits Revenue Act. The trust fund finances medical care and rehabilitation for miners with black lung disease and makes disability payments to them and to their surviving spouses and dependents.

Abandoned Mine Reclamation Fund. Fees that are structurally similar to excise taxes are levied on the tonnage of domestically mined coal and dedicated to the Abandoned Mine Land Fund, established in 1977 under the Surface Mining Control and Reclamation Act. The current fee is 35 cents per ton on surface-mined coal and 15 cents per ton on underground-mined coal or, alternatively, 10 percent of the value of the coal at the mine, whichever is less. For surface-mined lignite, the fee is 10 cents a ton, or 2 percent of the value of the coal at the mine. The Energy Policy Act of 1992 extended the authorization of the fees through September 30, 2004.

Gas Guzzler Taxes. Gas guzzler taxes are levied on domestic and imported cars with fuel-economy ratings of less than 22.5 miles per gallon. The tax ranges from $1,000 for cars that get at least 21.5 but less than 22.5 miles per gallon to $7,700 for cars that get less than 12.5 miles per gallon. Revenue from the tax is deposited in the general fund.

Taxes on Ozone-Depleting Chemicals. Taxes imposed on a variety of CFCs and halons as well as carbon tetrachloride and methyl chloroform are calculated as the product of a base tax amount and the specific chemical's "ozone-depleting factor." The base rate was set at $5.35 per pound in 1995 and has increased by $0.45 per pound per year. The amount of revenue collected, however, is small because production and import of most ozone-depleting chemicals are prohibited.

Proposed Increases in Excise Taxes That May Cut the Use of Fossil Fuels and Emissions of Carbon Dioxide

The Administration has proposed reinstating several taxes dedicated to the Oil Spill Liability Trust Fund and the Hazardous Substance Superfund (see Table 9). The taxes dedicated to these two funds expired a few years ago. Reinstatement would lead to price increases for oil and petroleum products and thus could indirectly result in reduced emissions of greenhouse gases. The Administration also proposed reinstating the motor fuel excise taxes dedicated to the Highway Trust Fund; those taxes were recently extended and are currently in effect through 2005.

Oil Spill Excise Tax. The President's budget proposes to reinstate the oil spill excise tax of 5 cents per barrel on domestic crude oil and imported petroleum products. The tax, which expired at the end of calendar year 1994, was dedicated to the Oil Spill

TABLE 9. ESTIMATES OF REVENUES FROM PROPOSALS FOR INCREASES IN EXCISE TAXES RELATED TO ENERGY AND THE ENVIRONMENT IN THE ADMINISTRATION'S 1999 BUDGET (In millions of dollars)

Proposal	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	1998-2003	1998-2008
Oil Spill Excise Tax	64	186	231	235	239	243	248	253	258	264	269	1,197	2,489
Hazardous Substance Excise Taxes	84	667	693	706	718	731	745	760	775	792	809	3,598	7,479
Total	148	853	924	941	957	974	993	1,013	1,033	1,056	1,078	4,795	9,968

SOURCE: Congressional Budget Office based on the Joint Committee on Taxation's estimates of the revenue effects of the Climate Change Technology Initiative in the President's 1999 budget

Liability Trust Fund to finance the cleanup of oil spills and other costs associated with oil pollution. The tax was not imposed for the calendar quarter if the unobligated balance in the trust fund exceeded $1 billion at the close of the previous quarter. The proposal would reinstate the tax from the date of enactment through September 30, 2008, and would increase the funding limit from $1 billion to $5 billion.

The JCT estimates that the proposal would increase revenues by $1,197 million through 2003 and by $2,489 million through 2008 (see Table 9).

Hazardous Substance Excise Taxes. The President's budget also calls for reinstating three taxes that were dedicated to the Hazardous Substance Superfund and expired at the end of 1995: an excise tax of 9.7 cents per barrel on domestic crude oil and imported petroleum products; an excise tax on listed hazardous chemicals at rates that varied from $0.22 to $4.87 per ton; and an excise tax on imported substances that use any materials in their manufacture or production that are subject to the hazardous chemicals excise tax. The taxes were dedicated to the Superfund for expenditures connected to releases of hazardous substances into the environment, under provisions of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980, as amended. The proposal would reinstate the taxes for calendar years 1998 through 2008.

The JCT estimates that the proposal would increase revenues by $3,598 million through 2003 and by $7,479 million through 2008.

Tax Preferences to Increase the Domestic Supply of Fossil Fuels

Several tax preferences in current law were designed to increase domestic production of oil and other fuels and reduce reliance on imports, particularly from the Persian Gulf region or politically unstable areas (see Table 10). To the extent that tax preferences lead to lower fuel prices, their effect may go beyond substituting domestic oil for imported oil to fostering increased consumption of fossil fuels. Tax preferences to encourage energy self-sufficiency may also result in more rapid depletion of national resources. In recent years, however, oil drilling activity has been low because of a drop in oil prices and cutbacks in certain tax benefits; as a result, preferences to encourage domestic production of fossil fuels would currently have little effect on emissions of carbon dioxide.

Expensing of Exploration and Development Costs for Oil, Gas, and Other Fuels. Firms engaged in production of oil, gas, or geothermal energy are permitted to expense (rather than capitalize) certain intangible drilling and development costs (IDCs), which include amounts paid for labor, fuel, repairs to drilling equipment,

TABLE 10. ESTIMATES OF TAX EXPENDITURES FROM PREFERENCES TO INCREASE DOMESTIC PRODUCTION OF FOSSIL FUELS AND REDUCE RELIANCE ON IMPORTS (In millions of dollars)

Tax Preference	1996	1997	1998	1999	2000	2001	2002
Expensing of Exploration and Development Costs							
Oil and gas	304	324	356	405	454	498	541
Other fuels	a	a	a	a	a	a	a
Excess of Percentage over Cost Depletion							
Oil and gas	418	471	489	508	529	550	572
Other fuels	85	143	145	148	151	154	157
Tax Credit for Enhanced Oil Recovery Costs	a	a	a	a	a	a	a
Expensing of Tertiary Injectants	a	a	a	a	a	a	a
Tax Credit for Production of Nonconventional Fuels	1,200	1,250	1,300	1,325	1,350	1,350	1,350

SOURCE: Congressional Budget Office based on estimates of the Joint Committee on Taxation.

NOTE: Tax expenditures are revenues that the federal government forgoes as a result of provisions in the income tax code that give selective relief to particular groups of taxpayers or special incentives for particular types of economic activity.

a Positive tax expenditure of less than $50 million.

hauling, supplies, and site preparation. For vertically integrated producers, expensing is limited to 70 percent of IDCs. That limit was set in the Tax Reform Act of 1986, which also repealed expensing on foreign properties. Additionally, IDCs are subject to the alternative minimum tax (AMT). The amount subject to the AMT is limited to 70 percent.

Excess of Percentage over Cost Depletion for Oil, Gas, and Other Fuels. Firms that extract oil, gas, or other minerals are permitted a deduction to recover their capital investment in the mineral reserve, which depreciates as the minerals are depleted. Cost depletion allows for the recovery of the actual capital investment over the period that the reserve produces income. Percentage depletion allows for the deduction of a fixed percentage of revenue from sales of the mineral. The percentage depletion method of deduction may and typically does exceed the amount of capital invested. Percentage depletion is allowed only for independent producers and owners entitled to royalties and only for up to 1,000 barrels of oil or its equivalent in gas per day. At present, about one-fourth of oil and gas production benefits from the subsidy. Percentage depletion for the major integrated oil companies was repealed in 1975.

The percentage depletion rate for oil and gas is 15 percent; a higher rate is permitted for marginal wells. The percentage depletion rate for other fuels ranges from 10 percent to 22 percent.

Tax Credit for Enhanced Oil Recovery Costs. The tax code provides a 15 percent credit for the costs of recovering domestic oil by a qualified "enhanced oil recovery" method. Qualifying methods are those that make possible the extraction of oil that is too viscous to be extracted by conventional methods. The costs of labor, repair of equipment, and injectants as well as the intangible costs of drilling and development, qualify for the credit, which is subject to the limits of the general business credit. The credit phases out over a $6 range for oil prices above $28 per barrel (adjusted for inflation after 1991). Current oil prices are well below the phaseout threshold.

Expensing of Tertiary Injectants. Tertiary recovery projects inject fluids, gases, and other chemicals into oil or gas reservoirs to enhance the recovery process. The tax code permits a deduction for the costs of the chemical injectants used in oil and gas production in the year in which the costs are incurred. Without incentives, tertiary recovery methods are generally uneconomic.

Tax Credit for Production of Nonconventional Fuels. The tax code provides a production tax credit of $3 per barrel (in 1979 dollars) for certain types of liquid and gaseous fuels that are equivalent to oil and are produced from alternative energy sources. The credit is phased out as oil prices rise from $23.50 to $29.50 (in 1979 dollars). Both the credit and the phaseout range are adjusted for inflation. Qualifying fuels include oil produced from shale or tar sands and synthetic fuels produced from coal. The credit is available through 2002 for facilities placed in service before 1993. For gas produced from biomass and synthetic fuels produced from coal or lignite, it is available through 2007 for facilities placed in service by July 1, 1998, pursuant to a binding contract entered into before 1997. The credit is offset by benefits from government grants, tax-exempt financing, and credits for energy, investment, and enhanced oil recovery. Apart from coal-bed methane, production of nonconventional fuels has hardly increased since 1980.[2]

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2 The use of coal-bed methane as a source of energy results in emissions of carbon dioxide instead of methane. Carbon dioxide is a less potent greenhouse gas than methane.

OTHER FEDERAL ACTIVITIES

Many other federal activities that appear in the budget may indirectly affect emissions of carbon dioxide and other greenhouse gases by altering the supply of energy or the demand for energy.

The federal government contributes to the supply of energy by:

- Producing power (Tennessee Valley Authority, Bonneville Power Administration, and four other power marketing administrations);
- Providing loans to rural electric cooperatives;
- Contributing to efforts to develop a nuclear waste disposal facility;
- Enriching uranium for use in nuclear power;
- Operating the naval petroleum reserves and protecting the oil shale reserves; and
- Leasing oil, gas, and other minerals onshore and offshore.

Although the government spends money on those supply activities, it also benefits from the substantial receipts they generate in the form of user fees, payments, and royalties.

The Low Income Home Energy Assistance Program (LIHEAP) provides assistance to low-income households in meeting the costs of heating and cooling their homes by making payments to eligible households and energy suppliers. States may target assistance to households with high energy needs and may assist households in reducing their need for energy. Budget authority for LIHEAP was about $1 billion in 1997 and 1998.

Transportation programs, in addition to those specifically cited above, may alter fuel use and carbon emissions. Over time, such programs may affect the total amount of travel (and, therefore, fuel used and emissions produced) as well as the type of travel chosen (substituting the amount of one type of travel for another can affect total emissions). For example, the Federal Transit Administration provides grants to transit operators and conducts transit planning and research activities. Emissions could either increase if spending raises the total demand for travel by boosting ridership or decrease (or stay constant) if rising ridership displaces automobile travel.

Finally, the federal government is itself a major user of energy. Gross energy consumption by the government is about 2 percent of all energy consumed in the

United States, with the government's energy bill totaling roughly $8 billion annually. The Federal Energy Management Program, described previously, aims to cut energy usage. Even if goals are met, however, the government would remain a major energy consumer and would be affected significantly by future policies to reduce carbon emissions.

The Kyoto Protocol on Climate Change
Fact Sheet released by the Bureau of Oceans and
International Environmental and Scientific Affairs
January 15, 1998

BACKGROUND

At a conference held December 1 - 11, 1997, in Kyoto, Japan, the Parties to the UN Framework Convention on Climate Change agreed to an historic Protocol to reduce greenhouse gas emissions by harnessing the forces of the global marketplace to protect the environment.

The Kyoto Protocol in key respects — including emissions targets and timetables for industrialized nations and market-based measures for meeting those targets — reflects proposals advanced by the United States. The Protocol makes a down payment on the meaningful participation of developing countries, but more needs to be done in this area. Securing meaningful developing country participation remains a core U.S. goal.

EMISSIONS TARGETS

A central feature of the Kyoto Protocol is a set of binding emissions targets for developed nations. The specific limits vary from country to country, though those for the key industrial powers of the European Union, Japan, and the United States are similar — 8% below 1990 emissions levels for the EU, 7% for the U.S., 6% for Japan.

The framework for these emissions targets is based largely on U.S. proposals:

- Emissions targets are to be reached over a five-year budget period as proposed by the U.S., rather than by a single year. Allowing emissions to be averaged across a budget period increases flexibility by helping to smooth out short-term fluctuations in economic performance or weather, either of which could spike emissions in a particular year.

- The first budget period will be the U.S. proposal of 2008-2012. The Parties rejected proposals favored by others, including budget periods beginning as early as 2003, that were neither realistic nor achievable. Having a full decade before the start of the binding period will allow more time for U. S. companies to make the transition to greater energy efficiency and/or lower carbon technologies.

- The emissions targets include all six major greenhouse gases. The EU and Japan initially favored counting only three gases — carbon dioxide, methane, and nitrous oxide. Ensuring the inclusion of the additional gases (synthetic substitutes for ozone-depleting CFCs) that are highly potent and long-lasting in the atmosphere provides more comprehensive environmental protection and lends more certainty concerning the treatment of the additional gases.

- Activities that absorb carbon, such as planting trees, will be offset against emissions targets. The treatment of these so-called "sinks" was another controversial issue at Kyoto. Many countries wanted sinks to be excluded. The United States insisted that they be included in the interest of encouraging activities like afforestation and reforestation. Accounting for the role of forests is critical to a comprehensive and environmentally responsible approach to climate change. It also provides the private sector with low-cost opportunities to reduce emissions.

Is the target the United States agreed to actually 7% lower than what the President proposed in October?

No. The 7% target represents at most a 3% real reduction below the President's initial proposal of reducing greenhouse gases to 1990 levels by 2008-2012. The remaining 4 percentage points result from certain changes in the way gases and sinks are calculated and do not reflect any increase in effort as compared to the President's original proposal.

Changing the baseline for the three synthetic greenhouse gasses from 1990 to 1995 accounts for about 1% of the 7% reduction. Use of these three gases has grown since 1990, so that permitting a 1995 baseline allows for a higher overall baseline than the Administration assumed last October when the President announced his goal of reaching 1990 levels by 2008-2012. Making reductions to meet a higher baseline is of course easier than making reductions to meet a lower baseline. Had the United States maintained the same level of effort assumed by the President in October, and no other factors had changed, the shift to a 1995 baseline for the three synthetic gases would,
alone, have transformed the President's goal of 1990 levels into a goal equivalent to 1% below 1990 levels.

Altering the accounting method for carbon-absorbing activities, such as planting trees, accounts for about 3% of the 7% reduction. The President's original goal assumed that the 1990 baseline would be lowered by carbon-absorbing activities, but under the method agreed in Kyoto, such activities do not lower the 1990 baseline. Because the 1990 level baseline is thus higher under the Kyoto agreement, the U.S. target becomes somewhat less stringent. Specifically, had the U.S. maintained the same level of effort assumed by the President in October, and no other factors had changed, the shift in the accounting method for carbon-absorbing activities would, alone, have transformed the President's goal of 1990 levels into a goal equivalent to at least 3% below 1990 levels. (As noted above, certain carbon-absorbing activities will count against emission reduction commitments in the budget period.)

INTERNATIONAL EMISSIONS TRADING

The United States prevailed in securing acceptance of emissions trading among nations with emissions targets. This free market approach, pioneered in the U.S., will allow countries to seek out the cheapest emissions reductions, substantially lowering costs for the U.S. and others.

Under an emissions trading regime, countries or companies can purchase less expensive emissions permits from countries that have more permits than they need (because they have met their targets with room to spare). Structured effectively, emissions trading can provide a powerful economic incentive to cut emissions while also allowing important flexibility for taking cost-effective actions.

The Kyoto Protocol enshrines emissions trading. Rules and guidelines — in particular for verification, reporting, and accountability — are to be discussed at the next meeting of the Parties at Buenos Aires in November 1998.

The inclusion of emissions trading in the Kyoto Protocol reflects an important decision to address climate change through the flexibility of market mechanisms. Led by the United States, the Conference rejected proposals to require all Parties with targets to impose specific mandatory measures, such as energy taxes.

The United States also reached a conceptual agreement with a number of countries, including Australia, Canada, Japan, New Zealand, Russia and Ukraine, to pursue an umbrella group to trade emissions permits. Such a trading group could further contribute to cost-effective solutions to this problem.

JOINT IMPLEMENTATION AMONG DEVELOPED COUNTRIES

Countries with emissions targets may get credit towards their targets through project-based emission reductions in other such countries. The private sector may participate in these activities.

Additional details may be agreed upon by the Parties at future meetings.

CLEAN DEVELOPMENT MECHANISM

Another important free market component of the Kyoto Protocol is the so-called "Clean Development Mechanism" (CDM). The CDM embraces the U.S. proposal for "joint implementation for credit" in *developing* countries.

With the Clean Development Mechanism, developed countries will be able to use certified emissions reductions from project activities in developing countries to contribute to their compliance with greenhouse gas reduction targets.

This Clean Development Mechanism will allow companies in the developed world to enter into cooperative projects to reduce emissions in the developing world — such as the construction of high-tech, environmentally sound power plants — for the benefit of both parties. The companies will be able to reduce emissions at lower costs than they could at home, while developing countries will be able to receive the kind of technology that can allow them to grow more sustainably. The CDM will certify and score projects. The CDM can also allow developing countries to bring projects forward in circumstances where there is no immediate developed country partner.

Under the Clean Development Mechanism, companies can choose to make investments in projects or to buy emissions reductions. In addition, Parties will ensure that a small portion of proceeds be used to help particularly vulnerable developing countries, such as island states, adapt to the environmental consequences of climate change.

Importantly, certified emissions reductions achieved starting in the year 2000 can count toward compliance with the first budget period. This means that private companies in the developed world will be able to benefit from taking early action.

DEVELOPING COUNTRIES

Various Protocol provisions, taken together, represent a down payment on developing country participation in efforts to reduce greenhouse gas emissions:

- Developing countries will be engaged through the Clean Development Mechanism, noted above.

- The Protocol advances the implementation by all Parties of their commitments under the 1992 Framework Convention on Climate Change. For example, the Protocol identifies various sectors (including the energy, transport, and industry sectors as well as agriculture, forestry, and waste management) in which actions should be considered in developing national programs to combat climate change and provides for more specific reporting on actions taken.

Developing countries may, as a prerequisite for engaging in emissions trading, voluntarily assume binding emissions targets through amendment to the annex of the Protocol that lists countries with targets. The Kyoto Protocol does not include a separate article for nations to voluntarily assume binding emissions targets.

Securing meaningful participation from key developing countries remains a priority for the United States. The Administration has stated that without such participation, it will not submit the Kyoto Protocol to the Senate for advice and consent to ratification.

MILITARY EMISSIONS

The Kyoto Protocol achieves the objectives identified by the Department of Defense where international agreement was necessary to protect U.S. military operations.

- Emissions from "bunker" fuels (for international maritime or aviation use) are exempted from emissions limits.

- Emissions from multilateral operations pursuant to the United Nations Charter are exempted from emissions limits. This includes not only multilateral operations expressly authorized by the UN Security Council (such as Desert Storm, Bosnia, Somalia) but also multilateral operations not expressly authorized that are nonetheless pursuant to the UN Charter, such as Grenada.

- Countries may decide, among themselves, how to account for emissions relating to multilateral operations (for example, U.S. training in another NATO country). This provision avoids the need to use emissions trading to allocate such emissions.

COMPLIANCE AND ENFORCEMENT

The Protocol contains several provisions intended to promote compliance. These include requirements related to measurement of greenhouse gases, reporting, and review of implementation.

The Protocol also contains certain consequences for failure to meet obligations. For example, as a result of a U.S.-proposed provision, a Party not in compliance with its measurement and reporting requirements cannot receive credit for joint implementation projects.

Effective procedures and a mechanism to determine and address non-compliance are to be decided at a later meeting. For both environmental and competitiveness reasons, the United States will be working on proposals to strengthen the compliance and enforcement regime under the Protocol.

ENTRY INTO FORCE

The Kyoto Protocol will be open for signature in March 1998. To enter into force, it must be ratified by at least 55 countries, accounting for at least 55 percent of the total 1990 carbon dioxide emissions of developed countries. U.S. ratification will require the advice and consent of the Senate.

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