S. Hrg. 103–56

ENVIRONMENTAL ASPECTS OF CURRENT HYDROGEN AND RENEWABLE ENERGY PROGRAMS

HEARING

BEFORE THE

SUBCOMMITTEE ON
TOXIC SUBSTANCES,
RESEARCH AND DEVELOPMENT

OF THE

COMMITTEE ON
ENVIRONMENT AND PUBLIC WORKS
UNITED STATES SENATE

ONE HUNDRED THIRD CONGRESS

FIRST SESSION

MARCH 22, 1993

Printed for the use of the
Committee on Environment and Public Works

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ENVIRONMENTAL ASPECTS OF CURRENT HYDROGEN AND RENEWABLE ENERGY PROGRAMS

MONDAY, MARCH 22, 1993

U.S. SENATE,
COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS,
SUBCOMMITTEE ON TOXIC SUBSTANCES,
RESEARCH AND DEVELOPMENT,
Washington, DC.

The subcommittee met, pursuant to notice, at 9:33 a.m. in room SD–406, Dirksen Senate Office Building, Hon. Harry Reid, chairman of the committee, presiding.

Present: Senators Reid and Harkin.

OPENING STATEMENT OF HON. HARRY REID, U.S. SENATOR FROM THE STATE OF NEVADA

Senator REID. The subcommittee will come to order.

The subcommittee today will receive testimony on the environmental aspects of current hydrogen and renewable energy programs. Such information is vital because the link or interface between renewable energy and the environmental goals that are pursued by this committee through legislation-resulting mandates is critical in terms of the future of the environment and the economic impact of our current policies.

I want to welcome Dr. Gibbons who is the first witness of a stellar cast. Dr. Gibbons is the new Director of the Office of Science and Technology Policy for the White House. Through Dr. Gibbons' leadership and the support of the new Administration, we have a real opportunity to move forward in the area of clean, sustainable, and renewable sources of energy.

I'd like also to mention that my colleague, Senator Tom Harkin of Iowa, is here today. He will be involved in this hearing as he has been with everything involving hydrogen since its inception as a policy decision. Without Senator Harkin's leadership, we would not be at the stage we are today. Senator Harkin has set an example that I've tried to meet in being a member of this committee and chairman of this subcommittee. He certainly has paved the way to make it easier for all of us.

I'm firmly convinced that hydrogen offers this country a bright and clean energy future. We have for far too long relied on fossil fuels as the basis for energy policy. The sad part about it is that we're going forward as if fossil is the only thing that is available. While we've made strides in the industrial sector throughout the century through our reliance on fossil fuels, everyone understands that the bill came due on the policy many years ago and we're going to be paying for it far into the next century.

Continuing to pass more environmental legislation, as surely this committe will do during this Congress, to deal with pollution and emission problems created by burning hydrocarbons typifies the way that energy policy has operated. We act actively, not proactively.

I think it is certainly appropriate to call attention to efforts that have taken place in California in dealing with the pollution emission environmental problem, particularly in light of the many witnesses here today from that State. There is no doubt in my mind that California has emerged as the leader in the field of environmental technology and clean air controls. In recent years, with all the economic problems in California, we tend to gloss over or even forget about the great strides they have made in being the environmental pioneers in most areas that we, as a committee, have worked.

Today, we have Dr. James Lents from the South Coast Air Quality Management District to discuss efforts by what is no doubt one of the leaders in the field of environmental air quality and related issues.

Witnesses from California corporations such as Sacramento Municipal Utility District, Lockheed, ARCO and Texaco have accepted invitations to appear here today because they are leaders in the field of research development and demonstration of various renewable energy technologies, and in particular, hydrogen-related technologies.

I didn't design this hearing in such a way that it would focus on California. It just happens that the State of California is on the cutting edge of these issues and for this, they should be very proud.

Senator Boxer is a new member of this committee. She's expressed a real interest in being involved in this hearing and she will be, as she will be in other activities of this subcommittee of which she's a member.

There is a wide range of hydrogen technologies that are being pursued in the research and development departments of many businesses, both small and large, across the country. That will be a matter of record at the conclusion of this hearing after the subcommittee has received testimony from the witnesses present here today.

Many of these technologies—such as the fuel cell and the use of hydrogen as a vehicle fuel—are not pie-in-the-sky technologies that won't be realized until the middle of the next century unless we condemn them to that fate. President Clinton and Vice President Gore have presented a new technology plan that will serve as a road map for this country to follow during the next few years and hopefully longer that will lead us in the direction of these new technologies.

The subject of hydrogen production and use is clearly a part of the plan. I look forward to hearing Dr. Gibbons' testimony regarding that and other elements of the technology plan.

Before I begin with the witness panel, let me say that a number of members of this subcommittee are traveling today and for other reasons cannot be present, including Senator Lieberman and the ranking member, Senator Smith of New Hampshire.

Also, my colleague from Nevada, Senator Bryan, who has worked with me shoulder to shoulder on this hydrogen issue, is also traveling today. His testimony will also be made a part of this record.

I also want to mention that Senator Lieberman has two companies in Connecticut that are involved in fuel cell development. Because of this and other reasons, he's interested in this issue.

Senators Smith and Bryan have submitted statements and they will be included in the record.

[The statements referred to follow:]

STATEMENT OF HON. BOB SMITH, U.S. SENATOR FROM THE STATE OF NEW HAMPSHIRE

FIRST, I WANT TO COMMEND CHAIRMAN REID FOR HOLDING THIS HEARING TODAY TO EXAMINE THE ISSUE OF HYDROGEN RESEARCH AND DEVELOPMENT AND ITS POTENTIAL FUTURE USE IN THE TRANSPORTATION SECTOR. I ALSO WANT TO SAY THAT, AS THE NEW RANKING MEMBER OF THIS PANEL, I LOOK FORWARD TO WORKING WITH HIM THROUGHOUT THIS CONGRESS ON THE MANY IMPORTANT ENVIRONMENTAL ISSUES BEFORE OUR SUBCOMMITTEE.

ALTHOUGH THE ENVIRONMENTAL BENEFITS OF HYDROGEN ARE WIDELY RECOGNIZED, WE NEED TO DETERMINE WHAT THE IMPEDIMENTS ARE TO THE COMMERCIAL DEVELOPMENT OF THIS CLEAN-BURNING FUEL AND HOW REALISTIC IT IS TO OVERCOME THESE IMPEDIMENTS. FOR INSTANCE, HOW DO WE SOLVE THE PROBLEMS OF STORAGE, DISTRIBUTION AND ECONOMIC FEASIBILITY?

WE MUST BE CAREFUL NOT TO ENCOURAGE NEW AND COSTLY ENVIRONMENTAL MANDATES IN ORDER TO HASTEN THE INTRODUCTION OF NEW TECHNOLOGIES. THE MOST REALISTIC AND PROMISING TECHNOLOGIES SHOULD BE PURSUED ON THEIR MERITS -- CONGRESS SHOULD NOT INVENT WAYS TO PROVIDE A REGULATORY HAMMER TO DRIVE RESEARCH AND DEVELOPMENT ACTIVITIES. FROM NUMEROUS ACCOUNTS, HOWEVER, HYDROGEN DOES HAVE A PROMISING FUTURE. IT IS CURRENTLY BEING USED IN THE U.S. SPACE PROGRAM AND HAS POTENTIAL FOR USE IN OUR EVERYDAY LIVES. IT SHOULD BE THE FEDERAL GOVERNMENT'S ROLE TO ENCOURAGE FURTHER DEVELOPMENT IN THIS AREA THROUGH INCENTIVES IN THE PRIVATE SECTOR. THE PRIVATE SECTOR IS WHERE COMMERCIALIZATION OF MOST NEW TECHNOLOGIES TAKES PLACE AND WHERE THE FUTURE MARKETS EXIST.

THANK YOU, MR. CHAIRMAN. I LOOK FORWARD TO THE WITNESSES' TESTIMONY AND LEARNING MORE ABOUT ADVANCES IN HYDROGEN TECHNOLOGY.

STATEMENT OF HON. RICHARD H. BRYAN, U.S. SENATOR FROM THE STATE OF NEVADA

First want to thank my Senior Colleague, Senator Reid, for his leadership in organizing this hearing. 1 believe developing a progressive energy strategy for our nation is inherently related to our future economic and environmental health. It is also an important element of our national security. The United States currently spends about a $1 billion each week to import oil that is polluting and non-renewable. As we seek to reduce our trade deficit, investing in alternative domestic energy sources makes both good economic and environmental sense.

As a new administration develops policy to lead us into the 21st century, the potential of renewable energy sources to become a major part of our energy mix, to reduce Follution and greenhouse gasses, and to create jobs through new energy technology, has never been so achievable.

The task, however beneficial, will not be easy. Conventional fossil fuels and nuclear energy have long received the bulk of our energy research and development dollars, and the constituency supporting that conventional energy infrastructure is a large and powerful one. The task of informing the public and educating policy makers about the benefits of new energy sources is formidable. In order to effectively promote the development of a robust renewable energy based economy, including renewables such as solar generated hydrogen fuels, we must:

*Reorient the U.S. Department of Energy's budget to direct new funds to renewable energy and energy efficiency programs while substantially reducing funding for nuclear energy research and development, conventional oil and coal research and development, fusion energy research, and costly projects such as the Superconducting Super Collider;

*Modify our tax policy to end subsidies of mature conventional energy technologies that pollute the environment, and which receive over 90% of all current energy tax benefits. Some of the revenue gained can then be directed through tax policy and direct expenditures to renewables that supply clean energy and reduce our dependence on foreign suppliers.

It has been estimated that such increased investment in sustainable energy technology could create as many as one million new jobs by the year 2000.

Solar energy is of particular interest to those of us representing the desert southwest, for several reasons. First, we have a rich and inexhaustible solar energy resource. Even with today's technology, a small fraction of Nevada's land area could supply the nation's energy needs if used for solar energy production.

The focus of this meeting, using solar energy to generate Hydrogen fuels for general use, is particularly exciting. Hydrogen is probably our best long term option for a general purpose, renewable fuel--it is non-toxic, does not contribute to global warming, and is of unlimited supply. It is also an ideal medium to store and transport solar energy to other regions which lack their own solar resources. It can also be generated in a variety of ways, including biomass as well as solar, so that a hydrogen based energy strategy will have a vast array of both production options as well as uses.

Unfortunately the development of solar energy and hydrogen fuels have both been hampered by our nation's inconsistent focus on energy policy and development. After making real progress in the late 1970's with the assistance of federal funding for research and development, renewable technologies languished in the 1980's as our research and development efforts concentrated on conventional fuels and nuclear energy. As a result, our dependence on foreign oil supplies increased, as did our emission of carbon gases into our environment.

We now have an opportunity to reverse course, and look to the energy technologies of the future rather than the past. Nevada is ready to be an active participant in this process. The State of Nevada is fully supportive of solar research, and we have the capability of dedicating the vast expanses of parts of the Nevada Test Site and other federal lands to this great endeavor.

Last year, along with my colleague Senator Reid, I offered an amendment which authorizes a year long study of the solar energy production and manufacturing potential at the Nevada Test Site. With our ideal location within the western electricity power grid in the United States, we in Nevada can play a key role in the transition to a solar/hydrogen economy by taking the first critical step--the large scale demonstration of solar electric production. We will do whatever is feasible and necessary to push forward with that first critical step.

I am hopeful that with the cooperation of the existing energy industry, the nation's utilities, environmental and energy regulators, and our policy makers, we can direct our nation on a progressive course to environmentally sound, energy independence. If we now make the first steps of that process possible, it may become our most lasting legacy to the citizens of the next century.

Again, thank you Senator Reid.

Senator REID. Before we begin the hearing today, I want the witnesses to know that we have your written testimony; we have a number of questions we want to ask; I have reviewed all of the written testimony that we have to this point; and I would ask that you try to confine your remarks to approximately 5 minutes so that questions can be asked.

Senator Harkin.

OPENING STATEMENT OF HON. TOM HARKIN, U.S. SENATOR FROM THE STATE OF IOWA

Senator HARKIN. Thank you very much, Mr. Chairman.

I would like to congratulate you for calling this hearing on hydrogen and to thank you for your kind remarks in my behalf. I've been advocating the development of hydrogen as an energy carrier for years going back to my years on the Science and Technology Committee in the House of Representatives.

I was first alerted to this form of energy as a possible energy of the future by our colleague, Spark Matsunaga, who really was the leader in hydrogen for many years until he passed away. I must admit at times since his death, I have felt like the lone drummer on hydrogen and it's been a little lonely. So I am really proud, Mr. Chairman, that you have come onboard and that you're now promoting hydrogen as an environmentally sound energy carrier for the twenty-first century. With your leadership on this committee, with your leadership in the Senate, and with some changes that are taking place downtown, I really believe we can make some tremendous strides forward.

Also, Mr. Chairman, I want to take this opportunity to thank Dr. Sandy Thomas of my staff who I obtained from the Office of Technology about three or four years ago, who has worked so hard and diligently on this issue.

Chances are if you went up to somebody on the street and asked what they thought about hydrogen as an alternative energy source, they'd probably think you were from Mars. Hydrogen research isn't exactly a household term. But if you went up to them and asked what they thought of a motor vehicle fuel that produces no acid rain and no smog, and no ozone-depleting chemicals, no carcinogens and no radioactive wastes, just pure, clean water, I'm sure they'd all be for it. That's the reality and the promise of hydrogen research. It is the environmentalist's dream.

Hydrogen could some day be the holy grail of environmentally sound energy. Our challenge today is to develop hydrogen products that are as good in practice as in promise.

Senator Matsunaga spent many years promoting this, culminating in the Matsunaga Hydrogen Act of 1990. The Matsunaga Act set up the Hydrogen Technical Advisory Panel and forced DOE to submit a 5-year hydrogen plan. It also required DOE to conduct small hydrogen energy demonstration projects, but so far DOE has not adhered to that part of the Matsunaga law. I hope that changes.

During the 102d Congress, I took the Matsunaga bill a step further. My bill accelerated the research and development of renewable hydrogen, which is hydrogen produced by nonpolluting domestic energy sources such as wind, solar, biomass or hydroelectric power. Most of the R&D sections of that bill were incorporated as Section 2026 of the Energy Policy Act of 1992 which President Bush signed last October.

The big difference between my bill and the Matsunaga bill is this. The Matsunaga bill laid the groundwork and permits the development of renewable hydrogen; my bill required the DOE to conduct the research into the production, storage, transportation and use of renewable hydrogen.

Unfortunately, this has run into the buzz saw budget politics and thus far, the budgets have not even come close to matching the potential of renewable hydrogen to provide a sustainable energy future for our Nation.

Mr. Chairman, just a quick sketch of the budget picture. R&D budgets at DOE have hovered around $1 or $2 million until last year when Congress increased it from $1.6 million, which was President Bush's request, up to $4.5 million. Again, even this small victory is watered down when DOE committed only $3.8 million for fiscal year 1993.

Fuel cells, a primary component, didn't fare much better. Fuel cells have been funded at $12 million. DOE's request for an increase to $21.5 for fiscal year 1994 was turned down initially by OMB which called for a freeze at last year's $12 million level. I've been pushing to increase it, Mr. Chairman, to $40 million.

Again, Mr. Chairman, we have the promise, we have the push here, but again, we don't have the budget to back it up. Quite frankly, Mr. Chairman, the DOE budget is still a cold war budget—67 percent of the DOE budget goes for atomic defense activity. We'll spend over $12 billion on nuclear weapons activities this year out of an $18 billion DOE budget. We can't even get $4.5 million for hydrogen research.

That still leaves 33 percent of the DOE budget pursuing applications, but even this remaining $6 billion is not directly related to solving our Nation's energy problems. Nuclear physics research is $309 million; high energy physics is $613 million; the Superconducting Super Collider is $517 million. Again, I'm not saying that these are not important, I'm all for basic research, but it's difficult to directly associate these physics research programs with our energy needs.

Then if you take a look at the $4 billion that's left over for actual civilian energy R&D, again, it's heavily-weighted towards the past. Fossil energy research is $921 million; nuclear fission research is $311 million; nuclear fusion research is $552 million. Again, when you look at those, when you look at how much is allocated to hydrogen, you can see that there really isn't a budget to back it up.

Right now, in terms of energy efficiency research, we're 50 percent the rate of 1979, 50 percent of what we were funding in 1979 and even worse than that, renewable energy research in 1979 was $1.3 billion and is now $211 million, six times less today than it was in 1979.

Senator REID. Not taking inflation into consideration either.

Senator HARKIN. No. So, we're way down. If you take into account inflation, it would be even worse than that.

Then if you look at hydrogen and fuel cells, renewable hydrogen is right now $3.8 million, not billion, and fuel cells, $12 million. Mr.

Chairman, I called for renewable hydrogen at $45 million which I think is just modest for this year and fuel cells at $40 million to get this up. So we've got to shift these priorities.

To that end, Mr. Chairman, I applaud you and the hearing you've set up today and the many distinguished witnesses you've invited. I'm particularly pleased to see Dr. Gibbons, the President's new science advisor, seated as the lead-off witness. Those of us who have been around Congress for many years have learned to appreciate and highly respect Dr. Gibbons' work and his work OTA. We eagerly look forward to his tenure at the White House.

I'm hopeful that they will continue to develop the new technology initiative announced February 22nd by President Clinton and Vice President Gore. This national technology plan includes a clean car initiative calling for the development of fuel cell electric vehicles to replace gasoline-powered, internal combustion engines. This clean car initiative is very similar to elements of my proposal for renewable hydrogen that was submitted to the Clinton-Gore Transition Team last fall. So I heartily endorse this major shift away from polluting, fossil fuel consuming vehicles towards clean-burning, fuel cell vehicles powered by hydrogen.

I look forward to working with the Administration to change the DOE priorities and to fully fund the new clear car initiative. The DOE budget must be restructured to support clean energy initiatives such as renewable hydrogen.

Again, Mr. Chairman, I congratulate you and I thank you for holding this hearing. I look forward to working with you and your staff to make sure that not only do we develop the hearing record on renewable hydrogen, but that we also get the funds necessary to carry out the needed research and development.

Thank you.

Senator REID. Dr. Gibbons.

STATEMENT OF JOHN GIBBONS, DIRECTOR, OFFICE OF SCIENCE AND TECHNOLOGY POLICY, THE WHITE HOUSE

Mr. GIBBONS. Mr. Chairman, Senator Harkin, I deeply appreciate your invitation for me in join you this morning. This is my first time giving testimony in the Senate since I undertook my new position. I'm very pleased that it's on a subject so vital to the long-term interests of the United States.

I do submit my full testimony for the record and would like to make a few comments.

I think we all understand that the age of fossil fuels is not over but the handwriting certainly is on the wall. The exhaustion of cheap resources, with the remainder being in very volatile places around the globe, gives us a special responsibility. We must think about future energy supplies, which require not years, but decades, to achieve. Mounting concerns about the distribution of fossil fuels and their manifold environmental impacts give us extra incentive to think about this transition, which may take 50 years.

We must move toward use of new technology, both to provide for more efficient ways to use our energy resources, and also to provide new energy supplies. As Senator Harkin so eloquently pointed out a few minutes ago, our practice in the past has been largely to ignore the renewable side compared to investments we've been making in fossil fuels and nuclear, both fission and fusion. It seems the time to redress this, to shift our balance, is overdue.

When I speak of renewable energy, I think of sunlight in a direct sense, but also solar-driven energy such as hydro, wind, and biomass, which can provide solid, liquid and gaseous fuel.

Senator Harkin, you're right. Renewables R&D has been the last in line in terms of public sector research. It has received very little attention, and I hope that this hearing and others will help shift this balance of attention.

Despite the lack of government attention, an extraordinary amount of progress have come over the last two decades. Advances in semiconductor technology, which have recently increased the cost-effectiveness of photovoltaic conversion, make an excellent example. Advances in chemistry and metallurgy have given us extraordinary advances in the techniques of fuel cells, gasifiers, turbines, and other technologies directly relevant to the use of renewable resources.

Genetic engineering is creating opportunities to increase the efficiency of biomass conversion. Electronics and electrical system, power engineering and electric controls, batteries, electrical capacitor energy storage—all of these things make the economic rationale for renewable energy much stronger because they greatly enhance the end-use efficiency of the resources.

The renewed national interest in renewables is driven by our concerns about our economy, our international balance of payments, our vulnerability to unrest in the Middle East, and our concerns about the environment. The Administration is going to support increased efforts in this area through increased attention to the research and development budgets, through new emphasis on corporate consortia, through joint ventures with the private sector, and through the use of government procurement powers—including acquisition of services, such as utilities, and products.

Perhaps most importantly, the Administration is concerned about providing better seed ground, through a variety of policy initiatives, for private sector investment in these areas. This concern appears as proposals for permanent research and experimentation tax credits, for capital gains treatments for small businesses, for technology extension services, and for a number of other things that will not only prepare a better seed bed for private investment, but also encourage partnerships between the public and private sectors.

As I see it unfolding, renewables will have their first impact in the electrical sector. We've already seen, for example, wind turbines reach the point that they are directly competitive in many areas of our Nation. Renewable energy-driven electrical supplies already have momentum in the niche markets.

The second major area for renewables that I'd like to touch on today is transportation. I don't want to go into the current problems we have with the automobiles, you know them as well as I do. Urban air pollution is, despite massive efforts to control at the tailpipe, largely driven by the automobile and light trucks.

We now use over 6 million barrels of petroleum a day for autos and light trucks. That's 85 percent of our current imports. It's headed toward 8 million barrels per day by the year 2010.

In our economy, the automobile sector is responsible for more than 10 percent of our manufacturing employment. You can go through a long list of American companies and see that this sector is an extremely important part of our national economy and merits close attention.

Therefore, the opportunity to align public and private interests in petroleum and the car is too good to pass up. You will hear much about this today. I will only say that the Administration, through the technology initiative, is trying to provide an opportunity for a true joint venture between our public and private sector to transform the automobile over the coming years. I won't say how many because we don't know yet.

It will be a combined effort within the government. The Departments of Energy, Commerce, and Defense, NASA and other agencies will be tapped in the areas for which they are best suited.

We hope to see internal combustion engines with their mechanical drives moving to alternative fuels such as compressed natural gas. That is but one of a series of steps as we move in the direction of transforming the automobile. Cars may eventually be driven by electrical systems fueled by hydrogen or other onboard storage. We see this as a way to get rid of the problem of pollution from the automobile. It is also a way to shift our sources of energy for the transportation fleet over to domestically available sources and certainly to a greater diversity of sources.

I think a very important long-term technology and science challenge is to improve the cost effectiveness of renewable fuels, especially hydrogen. The associated conversion technologies such as fuel cells, batteries and highly efficient electrical systems for power and control are also central. Efforts in these areas are very important to this Administration, and we certainly look forward to working with you.

Thank you, Mr. Chairman.

Senator REID. Mr. Gibbons, the cost of fossil fuel is seen in everything we do every day; the cost of government regulations that I talked about a little bit in my opening statement, our continual push here in Congress and on State levels to pass new laws and issue new regulations, all directed toward lessening the bad effects of fossil fuel.

It's no better illustrated than the oil spills that happen around the world on a weekly basis, as sad as it is. Hundreds of millions of gallons of fuel has been spilled into our oceans on a yearly basis. The cost of that, I don't think we can calculate. It seems to me that we should be extremely interested in conversion as quickly as possible.

I would mention to Senator Harkin and members of the panel, what we will do here today is have 10-minute rounds of questions until we run out of questions for each of the witnesses.

This morning I noted in your testimony, and you reiterated here in your oral testimony, 85 percent of the oil that we import is used for automobiles and light trucks. That doesn't talk about heavy trucks. That just talks about passenger vehicles basically—we import 6.1 million barrels of oil a day; increasing by 2 million barrels. That's why I wonder why we want to go to the Arctic to get a million barrels of oil a day, if we're lucky. It's a drop in the bucket as to what the real problem is. We should, in my opinion, declare war on fossil fuels and do what we can to convert as quickly as possible.

How do you think the Administration feels about the fact that fossil fuels are causing many of the problems we have in this country, economically and environmentally?

Mr. GIBBONS. I think you see the Administration's viewpoint in the rationale for the energy tax, which is not just a revenue-raising mechanism. As has been pointed out by the President and the Vice President, putting a tax on energy begins to make the price of energy reflect its real cost to our society, including environmental costs, the costs of maintaining security of foreign sources of oil, and other factors.

That's the first step, to try to get the energy price to reflect its true cost to society. As that price comes up, people start paying more attention to that price and alternative energy sources become more competitive.

Senator REID. The United States, it seems, only reacts under crisis. As you know, in the early 1970s when we had the first oil embargo, we went full steam in developing alternative energy sources—wind; that was the beginning of the tax incentive programs, especially in the California deserts where they had these windmill farms; solar was in its infancy then and there are companies here that will testify today that they started in this and then had to do it alone when the Government withdrew their incentives for companies to be involved in this kind of energy.

Now, we're hearing today, well, we have a tremendous supply of natural gas, so why don't we use natural gas for everything. Natural gas, as I understand it, has a finite supply. Is that not right?

Mr. GIBBONS. The extent of natural gas supplies depends on how much you're willing to pay for it. If you drill deeper and go to smaller pockets, there's a lot more gas. You're right, Senator, that it's a limited resource. It's one on which we, fortunately, can count for probably several decades, but certainly not for an indefinite future.

Senator REID. Batteries, we hear so much about batteries, but when you see them in a car or running your flashlight or whatever else, they seem so safe, but the fact of the matter is, it takes fossil fuel, in our present methods, to charge them, right?

Mr. GIBBONS. It takes a source of electricity, that's for sure.

Senator REID. Well, most of that is coming from fossil fuel.

Mr. GIBBONS. Most electricity comes from fossil fuels, in fact from coal.

Senator REID. So I think a lot of our environmental direction is kind of masked because we feel that batteries, because you don't see the smoke belching out of a car, is safe and it's the wave of the future. Even though we do recognize that batteries are better than some means of propelling vehicles, still to get the juice in the battery, it takes fossil fuel.

Mr. GIBBONS. Right, Senator. You have to think about the whole system and go all the way back to the original source of that energy in order to understand what its impacts are.

Senator REID. And hydrogen could be a source of generating that electricity.

Mr. GIBBONS. Hydrogen could be a source for generating electricity or, perhaps better yet, hydrogen could be a product of cheap electricity. If you can make it from a variety of sources——

Senator REID. Yes, biomass.

Mr. GIBBONS. And then use hydrogen where it has its highest value. For instance, hydrogen could be stored onboard an automobile for conversion with very high efficiency and no pollution, in a fuel cell to a direct source of power. In that case, you have the best of all possible worlds because you've removed the pollution entirely from the automobile and made the highest value use of hydrogen.

Senator REID. I think it speaks well for this Administration that the first congressional testimony given by the President's science advisor has been in a hearing dealing with ways to lessen our reliance on fossil fuels and improve the environment. The Administration is to be complimented and I certainly want your testimony to be underscored on that basis.

Mr. GIBBONS. Thank you, Senator.

Senator REID. In your written testimony—and you touched upon it here a minute ago—talked about hydrogen as a source of the future, but you've also indicated there may be ways of getting there more quickly. For example, conversion of natural gas into hydrogen, what do you mean by that?

Mr. GIBBONS. We are starting that process now with automobiles that have internal combustion engines. You can go across the other side of Capitol Hill today and fill your car with natural gas at a filling station over there. Some cars already use natural gas as a substitute for gasoline.

So as we chart the course to a hydrogen-powered system, we laid the groundwork for an infrastructure to distribute gaseous rather than liquid fuels. Once we have a fleet capable of using hydrogen, we can convert natural gas to hydrogen either at the filling station or onboard the automobile.

Future choices regarding fuels and propulsion systems will depend on the outcome of the technological studies and advances. There are tremendous opportunities to begin to move substitutes for petroleum to the pump and then to replace the internal combustion engine with some other propulsion mechanism.

Thoughtful progressive steps can lead us toward a hydrogen-powered economy.

Senator REID. There will be, after this hearing is completed, a demonstration of a hydrogen-fueled vehicle. It will be on the east front of the Capitol on the Senate side. Those interested in seeing a demonstration of hydrogen fuel, this is a pickup that's been converted to hydrogen. So that will be available today.

Finally, we're going to require, Senator Harkin and I especially, your leadership in helping us get a fair amount of money to continue research with hydrogen and fuel cells. Senator Harkin mentioned that right now, we're spending $4 million—$3.8 million actually, it was cut back—on hydrogen fuel research and development and $12 million on fuel cells. He has laid out the other figures for nuclear, well over a billion dollars. We need only a little bit of that to get started. So we're going to look to you for leadership and that of this Administration to help us in these very trying economic times to get our fair share of those monies.

Senator Harkin.

Mr. HARKIN. Thank you, Mr. Chairman.

Mr. Gibbons, thank you very much for your leadership through the years. I'm really glad you're down at the White House now. That's wonderful news.

Your statement is great. I want to point out a couple of things that perhaps you, in your abbreviated remarks, didn't cover, but I think they are very important.

On the second page of your written statement, you said that "The true value of these fuels must be measured in terms of full cost per mile driven." I hope you continue to drive that point home because if we look at it in that regard, then we begin to see a different picture emerge, not just what is the cost to put it in your tank right now, but what is it over the life span of the car in terms of the cost per miles.

Mr. GIBBONS. That's right, Senator. For example, as you move from hydrogen use in an internal combustion engine to hydrogen use in a fuel cell electric vehicle, you replace heavy, mechanical drive train systems with highly efficient electric motors. This drops the weight, which increases the efficiency. It's that whole system that one has to trade off. That is why we feel optimistic about the ability to move ahead without a significant change in total cost.

Senator HARKIN. There is a consultant, I won't mention his name publicly, maybe you know him, who used a basic Ford Taurus shell and through taking out all of the drive trains, the internal combustion engine, and putting in actually more than one fuel cell, three fuel cells, storage systems, the electric drive capacity, could actually put that in the shell of the Ford Taurus today, a full size car. The estimated price was about $1,000 more right now. That's at the present time. So there are people out there thinking about these things and designing these things right now.

Secondly, I think another important point is, you said "None of the economic comparisons I refer to here give renewable resources credit for other benefits not captured in standard economic accounts." For example, production of renewable resources can lead to economic development and employment opportunities, particularly in rural areas. It can lead to land restoration when abandoned or degraded farmlands are managed for sustainable production of biomass. For example, we've got all this CRP land and agriculture that is due to come out starting in 1996 and no one knows what to do with it.

Mr. GIBBONS. That's correct, Senator.

Senator HARKIN. They don't know what to do with it. What are we going to do with it? Well, by growing some of these biomass products, perhaps we can start looking at it in that direction. That is another, I think, important point.

Lastly, in regard to your testimony, you said "Dramatic action is needed." I think that is very true. You say, "We will be working closely with the automobile industry to design a program of research that not only helps U.S. industry produce the best vehicles in the world, but helps them build these vehicles with the world's most efficient manufacturing technologies." Okay, so far as it goes, but I hope you will look beyond also the standard automobile manufacturing.

I can only tell you what happened to me back in the 1970s when I was on the Science and Technology Committee in the House. I was working on a proposal then, a contract that NASA had with an automobile manufacturer, one of the leading three, to develop Stirling engine technologies. They dropped the contract, I went out to the company in Michigan to visit them to find out why, and they showed me this prototype of an engine they said was going to make all these breakthroughs and that Stirling was too far in the future. This new engine I recall was called a stratified charged engine, would really be the end-all and be-all for internal combustion engines. I daresay you still can't find one today anywhere in an automobile.

I guess my point in telling you that story is that there are some people out there who are putting up their own private resources, who have pooled other resources, and are coming up with concepts that are worthy of at least investigation. So I hope that you go beyond just the normal structure of the automobile manufacturers and look at some of these others too out there.

Senator REID. Would the Senator yield?

Senator HARKIN. Yes.

Senator REID. We've had, and I flatter Ford Motor company, I hope, by the fact that they are here today but frankly—this is a good opportunity for me to say it—we have not had the cooperation we should from the automobile manufacturers in this hearing.

I think that generally speaking, there are heavy reservations from the automobile manufacturers to move into this field, and we can't hide that fact. It is a fact, American automobile manufacturers, generally speaking, are hesitant and they have great reservations in moving into this field. That's been indicated by how difficult it's been for us to get cooperation for this hearing today from our major automobile manufacturers.

Mr. GIBBONS. I might respond to you briefly, Senator. The Administration is interested in more than just the large Chrysler, Ford, General Motors group in this regard. In the technology initiative, the primary thrust is encouraging small business—where the new jobs really come from in this country—by a variety of mechanisms. I mentioned some of those policies earlier.

At the same time, the big three are important, and I think to the extent that we can align public and private interest, we should work very hard with them. We know their interest is more focused on the near term. You would expect that since they are a very capital intensive industry in which, as they describe it, the ball game they have to play is one strike and you're out. So they have to be careful.

We hope we can help them in some areas of mutual, short-term interest, such as improved storage vessels for compressed gas onboard the vehicles and some advanced catalysts for pollution control. These are their practical, near-term problems.

We hope the quid pro quo will be that they, in turn, will join the public sector in really working hard on the transformation of the car to a low pollution vehicle capable of using secure, domestic sources.

Senator HARKIN. I hope that we do see some proposals from you, I'd be willing to discuss them at any time, at looking to incentives that we can give here—and they don't have to be very big—to get the fleet users across the country to start moving in this direction. We have centralized fueling operations, that type of thing.

We talked about that years ago and we've done just a little bit of it. There are some examples of it in some places in the country where we do have natural gas, for example, supplying fleet users, but it's just such a small fraction of the total out there.

Mr. GIBBONS. You're absolutely correct. We believe we can use the extraordinary purchasing power of the Federal Government to help effect change. As these technologies get closer to commercialization, Federal purchases can exert a strong pull forward. We hope that will be an instrument we can use.

Senator HARKIN. I look forward to hearing from your office for any proposals in that regard.

I would just follow up what our distinguished chairman has said about the funding levels. It's my understanding that DOE requested a modest increase to $5 million for fiscal year 1994, but OMB, as recently as last week, passed back only $4 million or less money than we appropriated this year. Can you enlighten us any and is there any hope that we can get this changed?

Mr. GIBBONS. As you know, this Administration is the first in American history to have to prepare a line-by-line budget in less than 90 days. We have been engaged with OMB in trying to see what adjustments can be made in this very near term and then begin to look very hard at fiscal year 1995.

I am pleased that fuel cell research is moving up from about $12 million to about $18 million, within DOE. And we should not focus just on one agency such as Energy, but look at the other agencies involved in this research such as Defense and NASA. We need to look at the whole budget and see how we can put those resources together.

Senator HARKIN. I'll pass down to you something that Dr. Thomas and I have worked on which is a program plan for near term funding that would, in 1994, put a total of about $87 million both into hydrogen R&D and fuel cells, and a few other smaller amounts in terms of some aircraft design concepts in terms of moving towards hydrogen concepts for aircraft. It's done line by line in terms of what I think could actually be used in the near term.

I would hope you would take a look at this and pass this on to people at OMB.

Mr. GIBBONS. I'd be grateful to have that, Senator. I certainly will give it a hard look and try to pass it on to the appropriate people.

Senator HARKIN. I would appreciate it very much because I do believe that amount of money could be more than adequate next year and not wasted at all.

That's about it, Mr. Chairman. I guess mostly it's just a matter of helping us move ahead in fuel cell technology. We know there are private companies out there already making fuel cells, selling them in the market, not for automobiles, but for stationary purposes.

There is a lot of private research that's going on and I think with just a small input from us in the amounts we've talked about we can really move ahead very dramatically.

Beyond that, I again would hope that the Administration will use its bully pulpit ability to bring what we're talking about home to the American people. As I said, if you go out and talk about—and I've done it—talk about hydrogen, people think hydrogen bombs and you want to build more hydrogen bombs, I thought we got away from that. Those who are older probably talk about the Hindenburg. Most young people don't know what the Hindenburg is, but somehow, we've got to get over that and bring home to people just what we're talking about. Using the ability of the White House to do that, I think can move us a long way on that.

One last question. Are you planning some type of central organization to coordinate and bring together the various technologies and capabilities that could be utilized in this clean car initiative? How are you going to structure it?

Mr. GIBBONS. We, of course, have been in contact with the major automobile manufacturers and other stakeholders, as well as with the various executive agencies that we feel have particular resources to add to this collection of work. We have reorganized one of the committees of the Federal Coordinating Council for Science, Engineering and Technology, FCCSET, that works on advanced manufacturing to make it the central place within the Executive Branch to put all these pieces together. We hope that the same thing will happen in the private sector as well so that we can get to work and begin to build enthusiasm on all sides.

It is OSTP's responsibility to arrange a successful merger of the various Federal activities and of the public and private interests. Our job is not to run the program, but to help catalyze the unified effort.

Senator HARKIN. Very good.

Thank you very much. I'll give you this list of things and I hope you can take a look at it. If you have any comments on any of those line items, let me know.

Senator REID. Also, even though Senator Harkin and I have not talked in detail in this regard, I think you should take word back to the White House that we're going to attempt to have the Senate speak to whether or not there should be more money spent on hydrogen. I don't think that $4 million is acceptable. I think we're going to have to try to educate the Senate about how imperative it is that we generously go forward on this relative to some of the money being spent on other scientific endeavors while just a pittance is spent for this.

I know that Senator Harkin and I will figure out a strategy to do that. If you happen to meet Leon Panetta in the hall, you might mention that to him.

Mr. GIBBONS. Thank you, Senator. I will.

Senator REID. One of the things that I think is also extremely important is that these new technologies be integrated into current DOE programs all around the country. Of particular concern, to me is the Nevada test site which has been going on for 40-odd years. With the cessation of testing that is going to take place in three years, it would be well that the multibillion dollar infrastructure is used for something of beneficial use, especially when witnesses later today will testify that vast amounts of our solar energy, that's where the sun shines, so to speak, is right in that area around the test site.

So, I would also ask that you be aware of the fact that there needs to be an integration of these technologies in some of our ongoing DOE programs and also some of our defense programs that are being terminated.

Mr. GIBBONS. I agree with you that we should examine carefully the resources at hand for more productive uses in the new post-Cold War world. Rather than trying to create new institutions, we should work very hard and diligently to orchestrate the resources we already have around this country.

Senator REID. Finally, Dr. Gibbons, I hope that you understand the mark that has been made on this institution, the Congress, with your leadership at the Office of Technology Assessment. I would hope that in recognizing that, you will do what you can, as I'm confident that you will, that you leave that same mark in this Administration's scientific endeavors. Our scientific endeavors have long since been overshadowed by other things. We would hope that we would have science become the hallmark of the new White House.

Mr. GIBBONS. Mr. Chairman, I'm honored by your remarks. I intend to use the lessons I learned so well with and through Congress to make OSTP the institution in the White House that it should and could become.

Senator REID. Thank you very much for your time here today.

Our next panel of witnesses will consist of Robert Williams, Princeton University School of Engineering; James Lents, Executive Officer, South Coast Air Quality Management District.

I might mention just in passing that I was first briefed several years ago on the work being done by the South Coast Air Quality Management District and was so impressed on that occasion that I have followed the work that is been done by them and have not been disappointed. It's great work that is being done and we're fortunate to have Dr. Lents here today.

Also with us today is Reinhold Wurster, who is here from Germany. He is the founder of a foundation that was among the first to seriously describe and demand a sustainable energy supply by using solar energy in combination with hydrogen energy storage.

As I indicated, this is a very distinguished panel. We're very fortunate to have all three of you here. What we would ask that you do is to submit your written statements for the record and summarize it in 5 or 6 minutes so that we can ask you questions.

We will first hear from Mr. Williams, then Mr. Lents and Mr. Wurster.

STATEMENT OF ROBERT H. WILLIAMS, PRINCETON UNIVERSITY SCHOOL OF ENGINEERING, CENTER FOR ENERGY AND ENVIRONMENTAL STUDIES, PRINCETON UNIVERSITY

Mr. WILLIAMS. Mr. Chairman and members of the committee, I am pleased to have the opportunity to testify at this important hearing.

I am a senior research scientist at Princeton University, Center for Energy and Environmental Studies, where I head a research group that carries out energy technology assessment and energy policy analysis.

For the last three years, I have been one of the coordinators of a study assessing the prospects for producing fuels and electricity from renewable energy sources. This study was commissioned by the United Nations Solar Energy Group for Environment and Development as input to the UN Conference on Environment and Development that was held last summer in Rio de Janeiro. The study has recently been published as a book, "Renewable Energy Sources for Fuels and Electricity."

My oral testimony, which relates to the wide use of hydrogen as a fuel for transportation, is drawn largely from the findings of this book, in the transportation area.

Continued reliance on gasoline-powered internal combustion engine vehicles as the dominant means of providing personal transportation services poses formidable challenges to the United States economy because of the implications for increased reliance on insecure sources of foreign oil, the difficulties of meeting air quality goals with further incremental reductions in tailpipe emissions, the prospects that concerns about global warming could lead to requirements for sharp reductions in dependence on fossil fuels, and the fact that the U.S. automobile industry has lost technological leadership and market share in both domestic and foreign markets.

The prospects are quite good, I think, that the use of hydrogen fuel cells for personal vehicles and other ground transportation systems would be able to meet these four challenges simultaneously. A fuel cell is not just another way to burn fuel; rather, the fuel cell moves energy conversion beyond the age of fire into the age of electro chemistry, providing a way to convert the fuel's chemical energy directly into electricity in a device with no moving parts. By removing the intermittent step of combustion to produce heat, the fuel cell offers a quantum leap in energy efficiency and the virtual elimination of air pollution.

Fuel cell electric vehicles can be powered by hydrogen or a hydrogen carrier such as methanol that is converted to hydrogen onboard the vehicle. In the case of methanol, the most likely carrier for the foreseeable future, this conversion can be accomplished by reforming the methanol onboard the vehicle with steam.

Both hydrogen and methanol can be derived from secure energy sources. It has already been mentioned that the least costly way to produce both hydrogen and methanol is from natural gas feedstocks. This can be accomplished with commercially-available technology that is widely used today in the chemical process industries.

The shift from gasoline internal combustion engines to natural gas-based hydrogen fuel cell vehicles can lead to very significant reductions in overall energy use. The natural gas energy required to power a fuel cell vehicle would be about 40 percent of the energy required for a gasoline internal combustion engine vehicle having comparable performance.

As natural gas supplies tighten in the future, additional supplies of hydrogen and methanol could be provided by thermochemical gasification of various biomass feedstocks. Biomass represents the least costly means of producing fuel cell vehicle fuels from renewable energy sources. The major candidate biomass feedstocks are urban refuse, agricultural and forest product industry wastes, and biomass crops grown on plantations dedicated to energy production.

Because fuel cell vehicles would be so energy efficient, even waste streams that we regard as minor potential energy sources could be significant. For example, about one-fifth of the projected fuel requirements for light duty vehicles in the year 2030, could be provided by hydrogen derived from urban refuse and urban wood wastes.

In industrialized countries, biomass produced on excess agricultural lands is the largest potential source of biofuels for fuel cells. The current amount of land that is held out of agricultural production, both for purposes of keeping up food prices and also for the purposes of controlling erosion would be adequate to support our entire light duty vehicle fleet at the levels of vehicle miles traveled that have been projected for the year 2030 by the Department of Energy.

The growing of biomass for energy this way would provide new sources of income for farmers that would make it possible eventually to phase out most government farm subsidies.

In developing countries, deforested and otherwise degraded lands with sufficient rainfall to support productive vegetation are the leading candidates for energy plantations. The amount of lands potentially available for such plantations in sub-Saharan Africa and Latin America are so large the these regions could become major exporters of biomass-derived transport fuels and thereby bring competition and price stability to international fuel markets in the long term.

Eventually, land and water resource constraints will limit further growth in the production of fuels from biomass, but large additional, though more costly supplies of hydrogen could be provided by electrolysis using wind, photovoltaic and solar thermal electric power sources.

As already noted by Mr. Gibbons, fuel cells would also have superb environmental characteristics, even taking into account the pollution associated with producing the fuels involved. Hydrogen fuel cell vehicles emit only water vapor and methanol fuel cell vehicles only carbon dioxide and tiny amounts of local air pollutants along with water vapor.

In addition, systemwide emissions of greenhouse gases from fuel cell vehicles will be dramatically less than for internal combustion engine vehicles. Even in the case of natural gas, greenhouse gas emissions would be reduced by more than half relative to the gasoline-powered internal combustion engine vehicles.

If fuel cells are to become an instrument for restoring the competitiveness of the U.S. automobile industry, they not only have to be clean and operated on secure energy sources, but also they have to be perceived by consumers as attractive alternatives to internal combustion engine vehicles.

Preliminary analyses indicate that fuel cell electric vehicles can be built with performance, range, and refueling characteristics that are comparable or superior to those for internal combustion engine vehicles. They would generally be more responsive, much quieter and would require less maintenance.

Though fuel cell-powered vehicles are at an earlier stage of development than battery-powered electric vehicles, they are likely to be attractive alternatives. They offer the advantages of battery-powered electric vehicles but they can be refueled quickly and the achievable range between refuelings would be probably much longer than for battery-powered electric vehicles.

Though the costs of prototype fuel cells are high and costs for routinely producing fuel cell electric vehicles cannot be determined with precision until engineering designs are more fully developed, some general considerations provide a basis for thinking that fuel cell vehicles would be competitive on a life cycle cost basis with gasoline-powered internal combustion engine vehicles.

Fuel cell cars would have fewer moving parts and would not have to be designed to contain explosive combustion processes. As a result, fuel cell cars can be expected to have lower maintenance costs. Moreover, because the fuel cell and ancillary equipment would last longer than the replaced internal combustion engine vehicle equipment, it is entirely possible that these components could be removed from retired vehicles and recycled.

Also because fuel cell cars would be two-and-a-half to three times as energy efficient as new gasoline-powered internal combustion engine cars, they would use much less fuel. This feature would make it possible for fuels derived from renewable sources to be competitive on a life cycle cost basis (measured in cents per kilometer traveled) even if the fuel price paid by the consumer is much higher than the price of gasoline on an energy equivalent basis, and even if the price of the fuel cell vehicle is considerably higher than the price of the internal combustion engine vehicle.

This is illustrated by Figures 5 and 6 in my written testimony which show that with both natural gas and biomass-derived fuels, life cycle costs would be less than for gasoline internal combustion engine vehicles and that even for electrolytic hydrogen sources derived from wind and solar sources, costing some $4 to $5 per gallon gasoline equivalent, costs per mile would only be a few percent higher than for gasoline internal combustion engine vehicles.

Senator REID. Mr. Williams, you time has expired. We've got a long hearing today and we have your testimony and we will follow that. We have some questions we need to ask you.

Senator REID. Mr. Lents.

STATEMENT OF JAMES LENTS, EXECUTIVE OFFICER, SOUTH COAST AIR QUALITY MANAGEMENT DISTRICT

Mr. LENTS. For the record, my name is Jim Lents. I'm the Executive Officer for the South Coast Air Quality Management District. We're the agency charged with solving Los Angeles' air quality problem. If you saw the air pollution there last week or last summer, that might put a question on my credibility as a witness, but I do want to point out that we have cut air pollution levels by 50 percent since 1977 when our agency was formed.

Senator REID. By 50 percent?

Mr. LENTS. By 50 percent. We were just so bad when we started, it's still horrible there and we've got a long way to go. But we're making progress.

I appreciate the kind words, Senator Reid, and the support for technology, you and Senator Harkin are providing by this hearing this morning.

We believe that hydrogen has a tremendous potential for dealing with the air quality problems in Los Angeles. As a way of background, we have the worst air quality in the Nation. Thirteen million people live there. If we were a State, we'd be the third most populous State in the United States, living with the worst air quality.

We believe, from studies that we've done, it's costing that area alone from $9 to $20 billion a year due to damage from air quality and about 80 percent of that is caused by energy production and energy use in the region. We're not doing Nevada, Arizona or other western States any favors either. We're a source of considerable visibility degradation in the Grand Canyon. I worked in Colorado before working in California.

Senator HARKIN. Mr. Lents, what was that $9 billion figure again?

Mr. LENTS. It's the health and materials damage that is occurring in Los Angeles.

Senator HARKIN. Health and materials damage.

Mr. LENTS. Yes.

Senator HARKIN. You've actually quantified that, obviously?

Mr. LENTS. Yes, we've done quite a bit of work on that.

Senator HARKIN. Would you supply me with some background?

Mr. LENTS. I sure will. We have reports on that.

As I was mentioning, in Colorado, when I worked there, 15 percent of the visibility degradation all the way into Colorado is due to California and fuel consumption that was going on in California. So there is a need not only for the citizens of Los Angeles to deal with this problem in California but citizens all over the United States.

In order to solve the problems in Los Angeles, it's going to take the development of new technology. In fact, about a third of our plan is devoted to forcing new technology and really in sort of an absence of leadership in the last decade, we'd have to take on more of that burden ourselves at the local level instead of the Federal level to try to make this new technology happen.

Our Technology Advancement Office, which we created, has a meager $8 million a year budget but it's large for a local agency to try to pursue technology development. We are operating a fuel cell at district headquarters. This is 200 kilowatts of energy. We are doing that with our local gas companies, so we've got them into the hydrogen business whether they meant to or not because they are taking natural gas and turning it into hydrogen.

We're supporting two programs for fuel cell buses, one in Canada and one here in the United States. We have some studies concerning polymer fuel cells; we are supporting the solar generation of hydrogen at the University of California at Riverside. We've just dedicated a solar electric vehicle recharging facility at the District and we are supporting a methanol-generating program at a local landfill that's going to make quite a bit of methanol out of landfill waste gas. We're doing some work with some solar Stirling engines.

We're spending more than 10 percent of our budget on hydrogen research. I think if the Government would come close to that, we would have the kind of money——

Senator HARKIN. Ten percent of your budget?

Mr. LENTS. On trying to do fuel cell work and hydrogen type stuff.

Senator REID. That's out of desperation, isn't it, because no one else is doing it?

Mr. LENTS. Yes, it's because no one is doing anything else. As I said, I feel like there's not been a lot done.

We're using the District fleet as a theory to test new fuels and have probably the most varied powered fleet in the United States. We just ordered 25 electric vehicles; we have a fuel cell vehicle ultimately coming that we've been supporting; and we have methanol and natural gas vehicles as well.

Senator HARKIN. But 10 percent of your budget is spent on fuel cells?

Mr. LENTS. Ten percent of our research budget is going in fuel cell and hydrogen work.

Senator HARKIN. Fuel cell and hydrogen?

Mr. LENTS. Right.

We're doing advocacy work also through the Ad Hoc Coalition for Fuel Cells which we helped to form and we also now have a Locomotive Propulsion System Task Force because even trains coming into the area represent a lot of emissions.

We would concur with the statement you made earlier that your budget is much too low. We realize that in times of budget stress, it's hard to argue for trying to put more money into projects, but we believe there's money in nuclear and coal research areas from where money could be transferred that would not damage those programs to put a little into these other areas. We'd urge that you look into that.

In conclusion, we're committed to cleaner technology. It's required for Los Angeles. We think as the rest of the United States grows, it is required elsewhere. Worldwide, our people are moving toward automobiles and single passenger vehicles and we're going to have to live worldwide with the consequences of that if we don't provide some leadership for cleaner, more environmentally safe technology.

Thank you.

Senator REID. Mr. Wurster. We appreciate your being here today. I know it wasn't easy but we appreciate it.

STATEMENT OF REINHOLD WURSTER, DIPLOM INGENIEUR, ARGE, MUNICH, GERMANY, OFFICE

Mr. WURSTER. Mr. Chairman, members of the committee, thank you very much for the opportunity to give some points of view from probably the German side of view.

First of all, I want to give an idea on my line of argumentation by providing some background information on my person, first of all, and then on the issue itself.

I'm active since about 4 years in the project management and project monitoring of the Euro-Quebec Hydro-Hydrogen Pilot Project which is a cooperative activity between the European Community and the Quebec Government. Whatever I will talk about of this project later on, it's referring to the European Project.

First of all, I would like to make some general remarks. If we talk about the selection of our future energy system or transport system, we have to take some strategic considerations. We all are aware of the greenhouse effect and the ozone depletion, but it is also population growth, you've heard today also the finiteness of the fossil resources, and environmental social, cultural, political, and industrial goals in general.

As we all know, it's very difficult to plan the future completely. Therefore, if we consider trying to take options for the future, we should choose such options which do not impose incalculable burdens on the future generations; we should select options which reflect, as we have heard today, the real costs of what we are doing and thus, we would avoid, more or less, the mislocation of funds.

We want to go them successfully into renewable energy as a basis for renewable hydrogen. We have to be aware that we have to take into account what sustainability, what it means to have environmental compatibility and, as one of the prerequisites, although often rejected, we have to think about an artificial increase on the related energy prices.

If we talk about a successful introduction of renewable hydrogen, there might be some opponents coming from the electric side talking about high temperature, super conductive storages. The technology is not yet available, therefore, we think we should stick to the technology available for storage and this is hydrogen.

Hydrogen will be, as we have heard today, a very important option for the transport section under the constraints which are imposed by the further use of fossil fuels. The first steps are the costs. Also in Europe, you know the European Community is discussing the introduction of CO_2 and energy effects. In Germany, we have the discussion about the steady increase of consumer energy prices. We are talking about some 5 percent per year so everybody, the consumer, industry, could adjust to the approach. The Swiss are talking about a system which is called the Eco Bonus System. They would increase energy prices and would redistribute the funds which they do not need, thus avoid per capita redistributed the administrative efforts.

On the other side, we know from an advisory commission to the German Parliament, that hydrogen and renewable can replace 70 percent of the end energy usage in the year 2000.

If we now come to the R&D programs, in the European-Quebec aspect, as well as in Japan, we can say that during the lst say 15 years, Germany was investing more or less some 20 million deutschmarks which is on the order of some $12 or $13 million US annually on hydrogen activities. So the German Government was the largest spender in hydrogen activities over the last 15 years.

As you know, there are a lot of products which have been shown in pilot demonstrations which never came to practical use, like the BMW and Mercedes process.

The budget for the German Ministry for Research and Technology this year is on the order, for all research activities, of 9.6 billion deutschmarks; 3.4 percent goes to the rational use of energy and renewable energy and in the total, 0.2 percent goes to hydrogen. So we have very comparable percentage relations like in the United States.

If you look at the Japanese, the Japanese have concluded a 27-year hydrogen program which will have a volume of 300 billion yen which is on the order of $2.5 billion US which may equally distribute some $100 million US per year uniquely for hydrogen technology. The background of this concept in Japan is the production of hydrogen from renewable resources, its conversion into a transportable form such as methanol.

The first hardware activity which is aiming at that is on the European and Quebec scale which is the Euro-Quebec Hydro-Hydrogen Pilot Project which did a feasibility investigation on the 100 megawatt scale plant providing liquid hydrogen for maritime transportation to Europe from existing hydropower resources in Quebec. This is a pilot project.

Since the financing for such a large project, which including all the applications technologies, would be on the order of $800 million US, since this financing is not yet secured, the project has continued as a platform for R&D and demonstration and the contracts which were signed up to now on the European side are on the order of 36 million ECQ which is about a little more than $40 million US.

Not to go into detail, at the point, I will give a speech at the National Hydrogen Association's annual meeting on Thursday and I have a paper prepared giving information about this project.

On the other hand, we know that we have to have strategic goals. From the view, the RENET Project from the Japanese, which is called the International Clean Energy Network Using Hydrogen Conversion, the so-called World Energy Network, and also the Euro-Quebec Hydro-Hydrogen Pilot Project, our platforms are focusing on certain goals.

If we now think about what can be done on the industrial level, we know that countries which invested very early in expensive environmental technologies became market leaders in that field. One of these countries in Japan and also Germany. This might be suitable as an example for an initiative on large scale introduction of renewable energy and renewable hydrogen also in this country.

We know also from Germany, and it is certainly similar here, that space and defense industries, but also the automotive industry, have a lot of knowledge available also in the field of environmental technologies. If you think about diversification strategies for these sectors, we should focus on complementary activities which are not in direct competition to the already ongoing hydrogen activities because they then never would succeed.

In case we mention boundary conditions, which I gave as an introduction, going to a sustainable system based on renewable energies and renewable solar hydrogen, it could open a very broad field of new industrial and commercial activity. We could look at the transport sector and we could start with public transportation with the buses and we could also go into cars.

Now I give one remark to the U.S. situation. You talk about zero emission vehicles in California. It now comes out step by step by zero emission vehicles are, of course, seen as electric vehicles, but these electric vehicles, due to the battery boundary condition, at least at the present will not be in the position to be operated without a fossil air-conditioning or ventilation.

If we accept this as a zero emission vehicle, we also should consider the internal combustion engine and lean mixture operation or a time of say 20 years before we have the commercial availability of the fuel cell technology. In this case, of course you have some emissions mainly coming from the burning of the lubrication oil but we could probably look at these emissions in the same way as we look on the fossil air conditioning. That's just something which came into my mind during the last days.

On the other hand, we could go into the small utility sector on the basis of biomass which is certainly a very promising field in the United States and also the large utility sector as the substitution in the long run for natural gas as well as in the short run, the spinning reserve application which we could take into consideration as a hydrogen application.

The main message which I wanted to convey is that we are not so much facing a technical problem, but probably more a political or a society-related problem.

Thank you.

Senator REID. I am glad that you're here Mr. Wurster, for a number of reasons. One is that this is not a problem of the United States only. Fossil fuels is not a problem of this country. We create far more than our share and we all acknowledge that, but with China now contemplating coming on-line with huge fossil fuel facilities, it should be pause for us all. I agree that the main problem we have in moving forward more expeditiously is a political problem, not a scientific problem. I'm not a scientist, so I can't validate that and that is why we're holding these hearings to have people like you who are pioneers in this field, validate it for us.

Mr. Williams, tell me what would you grow in these energy plantations?

Mr. WILLIAMS. What you grow in the energy plantations depends very much on regional characteristics. You have to select species that are attuned to the local climatic and soil conditions. In some parts of the country, you would grow fast-growing trees that would be harvested every 6 or 7 years; you might get three cuts out of a single planting. In other parts of the country, such as the Great Plains, you might instead produce fast-growing perennial grasses, which you would plant perhaps once a decade and harvest every year.

Senator REID. I see. We hear about the dangers and the evil of cigarette smoking and we're going to try to pass a tax that will basically put cigarette companies out of business, but I would submit that the ill effects from burning of fossil fuels far outweighs cigarette smoking. Does anybody disagree, any of the three of you? I'm not making light of the fact of how bad cigarettes are and how much they cost society, but I'll bet that the cost to us as a society from fossil fuels in the United States far outweighs that of tobacco smoke. True?

[No response.]

Senator REID. It doesn't appear, the record should indicate, that anyone disagrees with me.

Mr. Williams, would you be kind enough to explain on the record what a fuel cell is again?

Mr. WILLIAMS. A fuel cell is a device that converts fuel directly into electricity without having to first burn the fuel to produce heat. It operates very much like a battery in that regard but it differs from the battery in the sense that it has an external fuel source that is contained in a fuel tank. Most practical fuel cells will use hydrogen as fuel, but the fuel that you carry on a vehicle could either be hydrogen or some hydrogen carrier.

For example, I mentioned that a hydrogen carrier getting a lot of attention today is methanol. Methanol would be reacted with steam onboard the vehicle, thereby producing hydrogen plus CO_2. That mixture would be the fuel for the fuel cell.

Senator REID. The question I've been asked and I've been unable to explain is why do we need this process? Why don't we just use the hydrogen as a fuel source?

Mr. WILLIAMS. The main problems with hydrogen as a fuel are that it will probably be more expensive than gasoline, and it has a very low bulk energy density.

Senator REID. What does that mean?

Mr. WILLIAMS. That means large volumes are required for storing compressed gaseous hydrogen. For example, since hydrogen has roughly one-third the heating value of natural gas, three times the storage volume is required to get the same range from hydrogen as from natural gas when both fuels are used in internal combustion engine vehicles.

But if the hydrogen were used instead in a fuel cell vehicle, there would be a three-fold gain in efficiency that would roughly compensate for the much lower energy density, and the required storage volumes would be comparable.

Senator REID. How far along are we in the development of fuel cells? What I mean by that is, you as a scientist envision what a 100 percent efficiency would be, where are we now?

Mr. WILLIAMS. The only fuel cell that is commercially available today is the phosphoric acid fuel cell. This fuel cell will be used mainly for stationary power applications and in those transportation applications characterized by high duty factors and plenty of space. Its power density is not high enough to enable this fuel cell to fit in sufficiently high that you could put it into a light duty car.

For cars, an alternative fuel cell is needed, such as the proton exchange membrane fuel cell, which has been developed mainly for the space program and for military applications. Because of dramatic improvements over the last couple of years, it is worth seriously considering this fuel cell for use in light duty vehicles.

One recent development is the sharp reduction in the platinum loadings for the catalysts that are required at the electrodes in order to drive the reactions at sufficiently fast rates. This breakthrough makes it possible, if we were to move ahead with this technology and put it into mass production, for the fuel cell to compete with the internal combustion engine in passenger transportation.

Senator REID. Is there any doubt in your mind, Mr. Williams, that fuel cells will happen in the future?

Mr. WILLIAMS. I think the fuel cell will inevitably be the technology of choice for transportation. A big question is how fast the technology will be introduced.

Senator REID. A lot of that depends on how serious we are as a Government to assist the private sector in research and development, is that not true?

Mr. WILLIAMS. It's not just research and development that is needed, but research and development plus market stimulation efforts. The two have to go hand-in-hand. Industrial experience shows that technological progress and cost reductions occur not simply with the passage of time, but rather as functions of the cumulative sales of a particular product like a fuel cell. Thus, rapid market growth is needed, and efforts should be made to identify and aggressively exploit niche markets where fuel cells will be competitive before they can compete in light-duty vehicle markets.

For example, initial efforts in commercializing the proton exchange membrane fuel cell might focus on residential cogeneration applications, where the market value of fuel cells would be much higher than in transportation applications. For similar reasons, bus markets might be exploited before light-duty vehicle markets in transportation.

Senator REID. I guess I would ask you this, Mr. Lents, aren't you, in association with the State of California, by setting in the very near future certain standards for automobiles being sold in the State of California, in effect driving the niche that Mr. Williams is talking about?

Mr. LENTS. We're trying to. We've set a standard that by 1998, 2 percent of all vehicles sold in California be zero polluting and 10 percent by the year 2003.

Senator REID. That's a lot of vehicles.

Mr. LENTS. That's a lot of vehicles. There are close to a million vehicles sold every year in California, so by the year 2003, sales could reach 100,000 vehicles a year we hope are at zero pollution.

Senator REID. Mr. Williams, that would be a niche, wouldn't it?

Mr. WILLIAMS. That's more than a niche.

Mr. LENTS. We also actually have a secondary standard we call ultralow emission vehicles. The standards are so strict that at this point in time, some of the natural gas vehicles or hydrogen vehicles are the only type combustion vehicles that presently can meet the standards. That would represent an equal number, actually slightly greater. By 2003, we're thinking 15 percent to 30 percent be this type of vehicle.

Senator REID. Mr. Lents, would you describe for the record what Los Angeles would have been like had the South Coast District not cut emissions by 50 percent? What would it be like today in Los Angeles?

Mr. LENTS. It would be like Mexico City where birds are falling out of the sky dead, trying to fly through. I think Los Angeles would have no economy there because people could simply not live there if we had not taken steps. It's a problem because of the growth there and energy use. Every time we take two steps forward, we take one step backwards.

Senator REID. But at least you're gaining a step each time.

Mr. LENTS. Right.

Senator REID. I was impressed when I met with your office several years ago. I was shocked, surprised, and stunned, for lack of better words, when I learned that you were even going to limit the type of paint that could be applied to motor vehicles. I did not realize that when you add a million vehicles together, just the sun shining on the paint causes problem. You've got that specific, have you not?

Mr. LENTS. Oh, yes. There's very little automobile manufacturing in Los Angeles, but we set standards for furniture manufacturing, electronic products. All of that use creates quite a bit of air pollution. Also, on the reverse side, the ozone and pollution in the air does quite a bit of damage to finishes and paints in Los Angeles.

Senator REID. That's part of the property damage that you mentioned to Senator Harkin.

Mr. LENTS. Right. It forces people to replace it, so you get into this cycle of which you create air pollution by applying the paints and all but then the air pollution damage is faster and it has to be replaced faster.

Senator REID. Mr. Wurster, one of the things I could not fail to notice in your testimony was a comment suggesting that most European activities in the field of fuel cells are based on United States technology. Is that true?

Mr. WURSTER. That is true because also most of the Japanese activities are based on the U.S. technology, as you know. It was International Fuel Cells, by the trading company I think it was CETO, it was what was brought to the Japanese and they perfected the technology. Then they made the joint venture which then became the International Fuel Cells which I think is a daughter company of Toshiba and United Technologies. So basically, the old phosphoric acid fuel cell technology comes from the United States originally.

Senator REID. Mr. Wurster, could you tell us whether the European efforts are further advanced than those in this country in terms of the current state of development of fuel cells?

Mr. WURSTER. I don't think that they are further in the field of fuel cells. I think there the United States and the Japanese are leading. Five years ago, there was in Europe the opinion that there was a time lag in technology of at least five years. Probably we have made up this gap by two years or so.

Senator REID. I'm interested in what's going on with the hydroelectric production of energy in Canada being used for hydrogen fuel development. That's joint venture between your country and Canada, is that true?

Mr. WURSTER. No, it's not a real joint venture. Focusing on the Euro-Quebec Hydro-Hydrogen Project, this activity is just the technology program which uses as the background hydroelectricity in Quebec because it is the predominant energy source, clean energy source there, but we can see it as a vehicle not only for Quebec, but we can see it for all large hydropower resources in the world which are far away from the centers of consumption.

If you look at Africa, at the Zaire River, if you look at the northern part of Brazil, the Amazon River, if we can avoid the building up of hydropower plants, that's not so much the question; if we should support it is another question, but the point is that the electricity generated, for example, in Brazil in the Amazon River, is 2,500 kilometers away from the centers of consumption already now if you look at Sao Paolo and Rio. So there is quite a distance.

Of course you can bridge this distance with high voltage direct current transmission lines. That's clear but there will be also probably first applications of hydro like, for example, the direct reduction of iron ore which then would be completely environmentally compatible and probably not at higher costs than today if you do it at such locations where you have cheap hydropower.

Steelmaking contributes at least 10 percent to CO_2 emissions worldwide. So everybody has a contribution just of 10 percent to the CO_2 emissions like the automobile application as well. So we have many 10 percents and in the end it sums up to 100 percent, therefore, going into these niches first.

Senator REID. Senator Harkin.

Senator HARKIN. Mr. Chairman, thank you for the concise questions you were asking.

I want to ask Mr. Lents, as I understand the way the requirement is written in California, it's that 2 percent of each manufacturer's cars sold in the State of California by 1998 must be emission-free vehicles?

Mr. LENTS. That's correct, although we do allow the manufacturers to bubble in the sense that if the manufacturer comes up with an unusually good technology, they can do joint arrangements and one manufacturer can get credit for another manufacturer's sales.

Senator HARKIN. Secondly, I've heard rumors that California may be trying to back off from this. Do you know if there's any move to back off from that date?

Mr. LENTS. No, there's absolutely no move. There's just no way we can meet the mandates of either the Federal Clean Air Act or our own Clean Air Act and significantly back away from those commitments.

Senator HARKIN. I was wondering if each manufacturer has to meet the 2 percent requirement, it seems then what it does is it almost forces us, since we're only talking about 5 years from now, to move to a technology like battery technology which we know already which we could build into the cars right away. If we have some kind of provision that would allow for an exchange of credits like under the Clean Air Act for sulfur dioxide emissions where you can exchange credits, if someone is going to pollute more, someone can pollute less, they can exchange credits for a net reduction, and you say that is allowable? I did not know that.

Mr. LENTS. Yes, that is allowable under the system.

Senator HARKIN. So that an independent manufacturer, for example, of a fuel cell car could come in and sell obviously a lot more than 2 percent and trade that credit say with GM or Ford or someone like that?

Mr. LENTS. That's correct. In fact, I know of one set of negotiations going on right now where an electric car company has been doing some negotiations with one of the majors on maybe making up their share of zero emissions vehicles.

Senator HARKIN. Are any of you familiar with the Ballard Corporation in Vancouver, British Columbia?

Mr. LENTS. Yes, we've done joint projects with them. In fact, the fuel cell bus I referenced in my testimony that we are helping to support in Canada, the fuel cell manufacturer is Ballard.

Senator HARKIN. It's a 21-passenger bus operated entirely on the proton exchange membrane system this last winter and from what I've heard, it's operated fairly well.

Mr. LENTS. Yes.

Senator HARKIN. So this is a joint venture that you have?

Mr. LENTS. Yes. We are contributing money into the program.

Senator HARKIN. Who is we?

Mr. LENTS. South Coast Air Quality Management.

Senator REID. Senator Harkin, just one brief question. Why would you have a joint venture with Canada rather than some American company?

Mr. LENTS. We do with the Department of Energy but when we worked with the Department of Energy, their time lines started out like a 10 or 15 year program and we argued with them and got them down to about a 7 year program but the Canadians were willing in a matter of 2 years or so to actually put something on the road which they have done. We just felt like we had to support it because the time frames we're looking at don't give us a lot of time.

Senator HARKIN. I think, Mr. Chairman, we're going to have to have another hearing and we're going to have to bring our new Secretary of Energy and talk to her about this.

Senator REID. After she reads this transcript.

Senator HARKIN. Exactly.

I'm glad to hear that, because I think that obviously you in the South Coast would be interested in fleet uses of that whether it's buses or taxicabs?

Mr. LENTS. Yes, very much so. We have been looking at adopting a rule that would require fleets of vehicles to go to clean fuels. We have an experimental program right now with Federal Express that the Government has been supporting in Los Angeles where we are testing a lot of different fuels.

We think working with all of these various fuels helps develop all of them. For example, to the extent that we look at natural gas vehicles; we're looking at how you store compressed gas. That's critical for hydrogen vehicles as well. As we work with electric vehicles, we develop better electric motors and electric controllers, both of these you have to have for fuel cell vehicles. So we think there is a close relationship and a need to sponsor all of the various alternative fuels.

As I said earlier, we've converted a large fraction of our fleet to these new vehicles. The Federal Government seems like it would have a tremendous opportunity to do this and hasn't taken that opportunity either to support development by converting its own fleet or at least a sizable fraction of its own fleet to these new technologies.

Senator HARKIN. Mr. Wurster, how much is the German Government spending right now on hydrogen research and development?

Mr. WURSTER. About 20 million Deutsche Marks per year.

Senator HARKIN. 20 million?

Mr. WURSTER. 20 million Deutsche Marks.

Senator HARKIN. That's on all hydrogen?

Mr. WURSTER. That's on all hydrogen, including all technologies, not separated like I listened on the fuel cells and the hydrogen.

Senator HARKIN. Does the 20 million Deutsche Marks include fuel cells as well?

Mr. WURSTER. That means the major part in fuel cell development has to be brought up either by the companies themselves or by additionally trying to tap European funds.

Senator HARKIN. How much is that in US dollars?

Mr. WURSTER. It's about $12 million. It fluctuates very much due to our exchange and conversion rates.

Senator HARKIN. About $12 million US.

Senator REID. How much do the Japanese spend, does anyone know?

Mr. WURSTER. No, but in the future, and the future starts this year, it is from this year on, the 27-year program, the program will be on the order of 300 billion yen. You can change that now and the actual exchange rate might be on the order of $2.5 billion US over the 27 years.

Senator REID. How much per year?

Senator HARKIN. Wait a minute, I thought that was just 10 years?

Mr. WURSTER. No, it's a 27-year program.

Senator REID. How much would that be a year?

Mr. WURSTER. About $100 million, but this is pure hydrogen; renewables is addition on top of that. So this 2.5 billion yen is on the order of $12.5 billion US over 27 years. This is the data we have available by some contacts with the Japanese and which were confirmed by a governmental representative from the German Minister for Research and Technology who visited Japan in February. So it obviously is still in the planning stage.

I think in the National Hydrogen Association meeting on Thursday, there also will be a Japanese gentleman probably speaking on this topic.

Senator HARKIN. Mr. Williams, I want to thank you and Ms. Ogden for writing that book on solar hydrogen. From the first, it really got me going in this area. I think it's one of the substantial works done on pointing the way to using hydrogen as a fuel, especially solar hydrogen, renewable hydrogen.

Again, in your testimony, you pointed out I think in response to a question by Senator Reid, looking at the life cycle costs and the fact that using hydrogen rather than an internal combustion engine, using it in a fuel cell, that it is either 2.5 or 3 times as efficient.

Mr. Williams. It's a threefold increase.

Senator HARKIN. It is a threefold increase. I think economies can be developed again because we don't have to have so many moving parts in the car that the life cycle costs of owning one of those cars would be a lot cheaper. Again, we have to keep pointing out that.

In my opening statement I talked about the amount of money that we have invested right now in all the different forms of research, how much money do you think we could effectively use say if you looked ahead to next year and the year after both for fuel cells and for hydrogen? Do you have any figures in mind?

Mr. WILLIAMS. I cannot answer that question except to say that our commitment should be a lot more than at present. The amount that we spend collectively for hydrogen and for fuel cell vehicle research is about 0.6 percent of the total energy R&D budget in the United States. There has to be a dramatic reordering of our priorities.

One of the major challenges for policymaking today is to rearticulate what our economic, environmental and security goals are relating to energy and to assign new energy R&D priorities accordingly, across the board. What is needed is not large net new expenditures but rather a rationalization of the R&D expenditures that we're making for energy today. If our priorities were reordered to better reflect our needs, there would be a dramatic increase in what is going into areas like hydrogen and fuel cell vehicles.

Mr. LENTS. Senator Harkin, my technical staff believes that the research entities out there could effectively absorb ten times what we're putting into it now.

Senator HARKIN. Ten times what we're putting into both fuel cells and hydrogen. That's still not much.

Mr. LENTS. That still isn't much, $120 million.

Senator HARKIN. I've only asked for $87 million, so I'm still lowballing it, I guess. There are people telling me that there just simply isn't the research projects to use $87 million out there but your staff says that there is.

Would you take a look at my budget also and take a look at the different lines I have in there and see how it corresponds with what your staff has done, and if you've got some that I haven't looked at, would you please get those to me? I'd appreciate it. I'll have Dr. Thomas give you a copy.

Thank you, Mr. Chairman.

Senator REID. How large is your staff, Mr. Lents? How many people work for the South Coast Air Quality Management District?

Mr. LENTS. About 950 people are on staff at this point.

Senator REID. There are problems with hydrogen, at least it's been related to me and I want to see if these are significant problems. One is that hydrogen has a small molecular weight and it gives properties that make easy conversions of fuel sources difficult. It is so small it tends to leak through joints and metals. Is that true?

Mr. LENTS. Yes. It has a higher diffusion rate through pipeline materials. For example, if you're going to convert a natural gas pipeline to a hydrogen pipeline, you'd have to change valves, compressors and the like in order to deal with those kinds of problems.

Senator REID. But this is something that people know about. It wouldn't be anything unexpected. Everyone understands that, is that right?

Mr. LENTS. I think the Germans have the most experience with regard to the transport of hydrogen in industrial pipelines.

Senator HARKIN. They are already doing it.

Mr. WURSTER. We do that since more than 50 years. We have a 210 kilometer pipeline system in the rural area which even in World War II never was harmed, astonishingly, but this system is without any accidents since more than 50 years. So it is possible to do that.

It's also a question of now mobile transportation. We always state that annually we are transporting 100 million cubic meters of hydrogen on our highways, that's not possible. Of course it is possible, it happens every day and you do it here the same way, basically in liquid form.

Senator HARKIN. We do it from Alabama to Florida every time a shuttle takes off.

Mr. WURSTER. That's the reason why you have to do it in liquid form, not to carry just steel. If you would carry compressed hydrogen, it would be ridiculous.

Senator HARKIN. Can I ask a question, Mr. Chairman, to Mr. Williams?

Mr. Williams.

Senator REID. Of course.

Senator HARKIN. I've received conflicting estimates on this. How much hydrogen could you mix with natural gas in existing pipelines with existing valves and fixtures that would work? How much hydrogen percentagewise could you mix right in with natural gas right now?

Mr. WILLIAMS. I cannot give you a figure on that.

Senator HARKIN. I've heard as high as 20 percent, as low as 10 percent and just about everything in between. I can't quite put a handle on it. Maybe Mr. Wurster knows?

Mr. WURSTER. It depends also very much on your gas codes which are applicable in the different countries because it's not only a question of technology, it's also a question of the codes, what they permit. According to some German gas distributors, they don't see any problem according to the gas codes of up to 15 percent.

Senator HARKIN. Fifteen percent. You wouldn't have to change any of the seals, valves and things?

Mr. WURSTER. You would have to change. Especially what you would have to change is the measure equipment for the thermovalue. That's for sure. But as you probably change that today to electronic type of measurement, then it would be programmable and you could adjust that when you change your mixture ratios.

Senator REID. I think the point is in spite of these few things that we've talked about here, Mr. Williams, you talked about hydrogen as a fuel source being safe. Is that a fair statement?

Mr. WILLIAMS. It can be made safe. I regard all fuels as being inherently dangerous, and each fuel has to be treated with the respect that it deserves. The different fuels differ in their safety properties and in some respects, hydrogen is inherently safer. It is a very buoyant gas and in an accident, if there's a leak, it won't puddle like gasoline will. In other respects, it's more dangerous. It has a wider range of flammability and detonability in mixtures with air than any other gaseous fuel. But such problems can be dealt with, and we know how to deal with them. Hydrogen can be used with acceptable safety.

Senator REID. If you compare it to the other fuels now being used, there are those who say that if you started off from ground zero with hydrogen as compared to gasoline, certainly hydrogen is as safe if not safer than gasoline?

Mr. WILLIAMS. If it is handled properly and marketed properly, it can be as safe as gasoline, yes.

Senator REID. Mr. Williams, I've noted on page five of your testimony you make reference to photovoltaic resources and the need for only 0.2 percent of the U.S. land area to provide room for enough solar collectors to produce the hydrogen needed to run the entire U.S. light duty vehicle fleet. Do you remember making that statement?

Mr. WILLIAMS. Yes, that is in my written statement.

Senator REID. That certainly seems like a reachable goal, does it not?

Mr. WILLIAMS. Yes. If you look at each of the potential sources of hydrogen, each one has advantages and drawbacks. The advantage of natural gas is its low cost. But our natural gas supplies are finite.

Senator REID. Today, it's the cheapest.

Mr. WILLIAMS. Today, it's the cheapest and our gas supplies are finite. Biomass is the cheapest source of hydrogen from renewable energy. But because of the low efficiency of photosynthesis, a good deal more land is required than with photovoltaic sources. With hydrogen derived from biomass, about 4 percent of the U.S. land area would be required to meet the fuel requirements for all the light duty vehicles in the year 2030.

The problem with photovoltaic hydrogen is that it is more costly and it will be more costly in the future. But it could be produced in copious quantities, with very little land and water requirements for its production. Even though its cost measured in dollars per million BTU is going to be much higher than that for biomass and natural gas-derived hydrogen, the life cycle cost of owning and operating a car running on photovoltaic hydrogen will not be much different from the life cycle cost of the gasoline internal combustion engine vehicle.

Senator REID. There is certainly nothing that indicates it has to be an all or nothing proposition?

Mr. WILLIAMS. No. We have a diversity of supply sources for fueling a hydrogen economy.

Senator REID. Obviously the cheapest over a long term basis would be the sun?

Mr. WILLIAMS. With the exception of hydrogen derived from natural gas, all the other potential hydrogen supplies I have discussed in my testimony come from the sun. Hydrogen from biomass, wind, photovoltaic, and solar thermoelectric sources would all be derived, directly or indirectly from solar energy.

Senator REID. Senator Harkin, do you have anything further?

This has been a very good panel. As suggested by Senator Harkin, it's clear that this testimony will be closely reviewed by the Department of Energy. I think this is the foundation for having our own Department of Energy more involved in what's going on in LA and the rest of the country, and the world.

Thank you very much, all of you.

Our next panel of witnesses today will consist of Mr. Brad Bates, Manager of the Alternative Power Source Technology with Ford

Motor Company; Mr. Gary Noland, Lockheed Missiles and Space Company from Sunnyvale, California; and Mr. Bob Wichert from the Sacramento Municipal Utility District which coincidentally received a big story in the Washington Post yesterday.

We will first hear from Mr. Bates, then Mr. Noland and Mr. Wichert. Please proceed.

STATEMENT OF BRAD BATES, MANAGER, ALTERNATIVE POWER SOURCE TECHNOLOGY, FORD MOTOR CO.

Mr. BATES. Mr. Chairman, members of the committee, my name is Bradford Bates. I am the Manager of the Alternative Power Source Technology Department at the Ford Research Laboratory. Ford appreciates being asked to comment on the utilization of hydrogen as a transportation fuel and I hope the following remarks will be useful.

Ford has had hydrogen fuels under active consideration for over a decade. At this time, we're having Dr. Kukkonen update his assessment of hydrogen fuel. His SAE paper, 810349, "Hydrogen As An Alternative Automotive Fuel," remains a benchmark paper. I request that his work be included in the record of this hearing. [The paper referred to has been retained in committee files.]

Senator REID. That will be the order.

Mr. BATES. We consider ourselves one of the leaders in the application of alternative fuels and hydrogen is one of the possibilities. Ford is committed to continuing its investigation of the use of hydrogen and that is one of the reasons that my department was recently established at the laboratory.

Hydrogen may have a role as a transportation fuel. It offers some exciting potential and many opportunities for technical innovation and development of enabling technology required for its use. The timing for this is expected to be well into the next century, however, planning and research efforts need to be undertaken now to prepare us for the use of this fuel when it is economically available.

The research must be carefully coordinated and very well managed to avoid redundant or wasted efforts. A thorough analysis of the entire challenge, including production, transportation, storage offboard, fueling, storage onboard and its use in the vehicle must be done to develop a scenario for use of hydrogen as a transportation fuel.

It is likely that there will be two different scenarios, one using expensive hydrogen as produced by methods known today, and one using inexpensive hydrogen produced by methods yet to be developed. Both of these scenarios must be customer-driven in order to yield a successful vehicle. That is, the needs of the ultimate transportation customer must be the driving influence for any viable scenario. Once the scenarios are agreed, the enabling technologies can be identified and prioritized. At that time, research should be undertaken to develop the required technical foundation for the use of hydrogen in transportation.

A potential scenario uses a fuel cell to convert the hydrogen into electricity and electric vehicle technology for the drive. This is a particularly exciting possibility as both fuel cells and electric vehicles are presently under development and this scenario is projected to be the most efficient use of hydrogen. There still remains, however, the need to address the infrastructure issues of production, distribution and storage.

With respect to the specific questions raised in the letter of February 16, 1993 from Senator Reid, I'd like to offer the following comments.

First, hydrogen fuel transportation is one of many environmental technologies that are being developed. Keeping in mind my comments with respect to ensuring the total systems approach for the use of hydrogen, efforts to utilize this technology are proceeding at a reasonable pace and for the most part in appropriate enabling technology.

Second, the environmental benefits for the use of hydrogen as a transportation fuel are well understood with respect to the end use. Hydrogen can be used with little environmental impact at that point of use. The bigger picture of the total environmental impact, including the production, transportation and storage of hydrogen must be more completely analyzed.

Third, barriers to the development of hydrogen-powered transportation appear to be largely technological. This could change as we gain a better understanding of total infrastructure required for hydrogen utilization.

Fourth, the most appropriate steps at this time to ensure that hydrogen remains as a viable candidate for transportation fuel include the detailed planning of a viable hydrogen fuel use scenario that would meet the needs of the customers. This effort could lay the foundation for the identification of research required to develop enabling technologies that will be utilized for hydrogen fueled transportation.

Fifth, the potential use of hydrogen as a fuel is well into the future, while we must not be complacent about the issues of U.S. competitiveness, at this time, it does not appear as though there is any significant risk that foreign investment could adversely affect U.S. competitiveness.

Some recommendations. An effort should be initiated to combine proposed hydrogen use scenarios into two plans, one assuming hydrogen available from known production methods and one assuming inexpensive hydrogen available from methods yet to be developed.

Given viable customer-driven scenarios, the fundamental enabling technologies required for success should be identified and prioritized. Funding should be made available to encourage research and development of enabling technologies and an appropriate organization must be identified that can carefully manage this whole process. Plans should be developed that can guide this process for at least the next decade.

Thank you for asking us to participate in this session. If you would like further information on hydrogen fuels, we'd be happy to meet with you again. If there are any question with respect to my comments, I'd be happy to answer them.

Senator REID. We will have some questions for you and the others after we hear all the statements.

Mr. Noland, would you please proceed?

STATEMENT OF GARY NOLAND, LOCKHEED MISSILES AND SPACE CO.

Mr. NOLAND. Thank you, Mr. Chairman.

I'd like to thank you for inviting me today to participate in this hearing on renewable energy sources and hydrogen research and development activities. I feel particularly privileged to be participating today and to be associated with the other witnesses who are providing testimony.

I think it's quite appropriate that the Environment and Public Works Committee consider issues associated with hydrogen energy development for the U.S. The move toward reducing our dependence on fossil fuels, particularly imported oil, in favor of clean, domestically-produced hydrogen energy clearly has positive environmental impacts for the Nation.

At the same time, the need to develop and implement infrastructures, as my friend from Ford has just mentioned, to produce and deliver hydrogen to the American public could represent substantial public works programs employing a large number of Americans in high-skilled, high-paying jobs.

Considering the activities needed to implement a hydrogen infrastructure, in conjunction with a green car, using hydrogen as a fuel, is certainly prudent on the part of the committee. I applaud your efforts in that regard.

The defense aerospace industry maintains an interest in high energy density power systems, hydrogen storage and fuel cells for use in a variety of military applications such as spacecraft, land vehicles, unmanned underwater vehicles and other applications.

To prepare for these future applications, ARPA has been supporting fuel cell-related research for a number of years. Most of this work has focused on developing high energy density storage systems for the unmanned underwater vehicle activity which could have direct application for the problem of storing hydrogen onboard an automobile and used with a fuel cell.

The concept of applying DOD-related technology developments to non-DOD problems has a great deal of merit and these technology developments should be shared with the auto industry to assist with the development of fuel cell electric vehicles.

In addition to development of hydrogen technologies for fuel cell electric vehicles and other applications, the aerospace-defense industry could assist with component development for use in environmentally sustainable systems for hydrogen production, storage, transportation and distribution, that is development of a hydrogen infrastructure.

The most cost effective approach, I believe, has been mentioned earlier today and would initially be producing hydrogen based on extracting hydrogen from fossil fuels, particularly the reforming of natural gas and the gasification of coal. As you know, the United States has substantial reserves of both these natural resources.

In the future, however, solar-powered sources of hydrogen need to be developed to produce hydrogen without exhausting the CO_2 and other harmful gases and to eliminate our dependence on fossil fuels for our transportation sector. These are areas in which the defense-aerospace industry could provide research assistance.

Clearly, the single biggest need to promote development of fuel cell electric vehicles and the necessary support for a hydrogen infrastructure is to substantially increase the priority and funding levels at the Department of Energy for renewable energies in general and for hydrogen systems in particular. In addition, an initiative by President Clinton with strong congressional support for development of a "Green Car" based on clean hydrogen energy would provide a highly focused program to achieve an objective with both environmental and economic benefits for the American people.

Finally, partnerships between government, academia, industry and the public sector are a vital ingredient in the formula for success of a program aimed at developing end-use systems based on clean hydrogen energy and an infrastructure for providing that hydrogen to the American public.

That concludes my testimony. Thank you.

Senator REID. Mr. Wichert.

STATEMENT OF BOB WICHERT, SACRAMENTO MUNICIPAL UTILITY DISTRICT

Mr. WICHERT. I want to express our sincere gratitude to you, Senator Reid and Senator Harkin, and Mr. Reynolds for allowing the Sacramento Municipal Utility District the opportunity and the honor to talk and participate in this important work.

I coordinate the Advanced and Renewable Technology Development Program for the Sacramento Municipal Utility District. We are a reasonably large municipal electric utility in California dedicated to clean, efficient, electrical power. The purpose of the Advanced and Renewable Technology Development Program is to eventually build 350 to 400 megawatts of advanced and renewable generation in about the year 1999. Our efforts in the interim are designed to use advanced or renewable technologies on a small scale.

Senator REID. How many megawatts was that?

Mr. WICHERT. 350 to 400 megawatts.

Our intentions in the interim are to use small amounts of these advanced and renewable technologies on our system to bring down costs, improve reliability, gain experience with these technologies, all designed to give us a long menu of clean, efficient, renewable technology when we need to make our decisions in about 1996 or 1997.

We are also striving to electrify the transportation sector in Sacramento County, which is our service area. We are doing that to improve air quality and to try and get air quality moving in the right direction in Sacramento County. Currently, we're not making big improvements there but we think electrification of the transportation sector can really help do that.

It is absolutely clear that renewable hydrogen can help us meet that goal. Renewable hydrogen produces no pollution whatsoever, no toxic wastes. It can be applied to both transportation and stationary power applications. It is truly a zero emission technology.

We might skip over that quickly but let's dwell on that for a second. A zero emission vehicle that produces no emissions at its tailpipe and also produces no emissions at the power plant is truly a zero emission vehicle and a renewable hydrogen fuel cell vehicle meets that definition.

People ask me, is this R&D. I reply, no, this is not R&D. We're an electric service utility. We don't do "R," we do development and demonstration and we have an emphasis on demonstration. If I have a message here today, it is that integrated demonstration projects are absolutely necessary to move these technologies forward.

We have one that we're trying to pursue. It is a solar hydrogen fuel cell bus. This is just one example of a possible integrated project. It takes photovoltaics and electrolytically separates water into hydrogen and oxygen, stores the hydrogen for use on the fuel cell bus. That way, we have not only production facilities but an end use, a bus. This kind of project will allow fuel cells and hydrogen to work together for the benefit of both technologies.

There are other ways to make renewable hydrogen. Biomass has been mentioned and we're very interested in biomass. As a matter of fact, we're doing a study with the University of California at Davis to try and find which biomass technologies might be best applied in our area to produce renewable hydrogen from biomass.

This kind of work could produce an integrated project where 600 or 700 acres of land might be dedicated to grown fuel which would then produce hydrogen for use in a 2 megawatt fuel cell power plant, again an integrated project with production and end use together as one. This could return quite a bit, millions of acres actually, of agricultural land to production, valuable production producing one of our most valuable products which is electric service.

The United States must compete in an international marketplace. That is clear. The United States industry has quite a bit of experience with both liquid and pressurized hydrogen. Most of the applications are defense or aerospace-oriented but they could easily be converted to power or transportation use. The challenge is making these technologies meet the needs of the citizens of the United States while also competing in the international marketplace because clearly other countries have done more. As we've heard earlier, the Japanese, the Germans, the Canadians are all doing much more than we are in fuel cell and renewable hydrogen technologies.

The first fuel cell bus recently rolled out in Vancouver and we congratulate the Canadians on that significant achievement, but we would like the DOE program to do as well or better. We would like our solar hydrogen fuel cell bus to be part of the DOE program to do as well or better than the Canadians. Federal leadership is absolutely essential. The establishment of a Hydrogen Implementation Board will help focus our efforts.

This work can bring the technologies originally pioneered in this country back to our workplace to allow our industry to reap the benefits of what might be the transistor of the 21st century.

Thank you.

Senator REID. Mr. Wichert, yesterday, as I mentioned, the Washington Post in the first section, page three, ran a story about your problems and your successes, basically. The voters there voted to close down the nuclear power plant that supplied almost 900 megawatts.

Mr. WICHERT. It was about 900 megawatts, that' right.

Senator REID. Which is a lot of power. You've managed to survive in those years by purchasing power from other places and now it's my understanding that you have four cogeneration facilities that are on-line and in the process of being constructed; fueled by natural gas, is that right?

Mr. WICHERT. We're in the process of licensing those advanced high efficiency, natural gas cogeneration plants, that's correct.

Senator REID. In addition to that, you're looking at alternate energy sources to produce some 300 megawatts that you will still be lacking, is that right?

Mr. WICHERT. It will be 350 to 400 megawatts I discussed earlier to come on-line in 1999 which will be from advanced and renewable technologies. I don't know if the article mentioned it, but we also have commitments to build a 50 megawatts wind plant in the near term.

Senator REID. No, it did not.

Mr. WICHERT. In about 1995. Additionally, we are pursuing 700 kilowatts of photovoltaics this year to add to the 2 megawatts of photovoltaics that we already have.

Senator REID. To get an indication of how much 350 to 400 megawatts would be, I traveled a number of years ago down to the Luz facility in Mojave, California to look at their solar facility. That's 200 megawatts. It's my understanding, or at least it was then, I don't think things have changed, the next largest facility producing electricity by solar energy is 20 megawatts?

Mr. WICHERT. The numbers are certainly reminiscent of what we have heard. I would like to make it clear that we're not going to necessarily build 400 megawatts of solar technology.

Senator REID. I understand that, but my point that I was making is that 40 megawatts is a lot of power. It's twice as large as the largest facility that's now in existence.

Mr. WICHERT. You're absolutely correct, that's right.

Senator REID. In your testimony, you suggest there are numerous demonstration projects that are ready to move forward in the field of fuel cell and hydrogen technology. Is that true?

Mr. WICHERT. Absolutely.

Senator REID. Upon what do you base that?

Mr. WICHERT. We've watched the work done by many companies in this country and other countries. We've watched the Canadians build a fuel cell bus; we've watched the energy partners group in Florida work on their PEM fuel cell car; we know about work that the South Coast Air Quality Management District is pioneering to put fuel cells on trains; we've also talked with international fuel cells and other manufacturers in this country about fuel cells that might be applied in transportation and utility applications. We are also buying two 200 kilowatt fuel cells from International Fuel Cells to be put on our system in 1993 and 1994.

Senator REID. There's little doubt that you believe, in reviewing your testimony, that hydrogen will be a part of our energy future. In fact, you suggest it takes about 10 years from the time you have a demonstration project to actually have it effective. Is that what you say?

Mr. WICHERT. We plan to work for the next—actually last year also, 1992—for 1992 through 1996 or 1997 to pave the way for plants that we plan to put on-line in 1999. The year 1999 is tomorrow in the utility business and we think the time is now to demonstrate some of these projects.

Senator REID. According to your testimony, SMUD spent $1 million last year on hydrogen-related research.

Mr. WICHERT. Our current budget has about $1 million on hydrogen, renewable hydrogen and hydrogen fuel cell applications, specifically the SMUD solar hydrogen fuel cell bus. There are additional monies being spent on fuel cells; the 200 KW fuel cells are additional to that.

Senator REID. Senator Harkin, it goes without saying that we, as a country, should be I don't want to use the word embarrassed, but that's the best I can find.

Senator HARKIN. One-fourth of our whole hydrogen budget.

Senator REID. That's right. I think you have 500,000 customers, is that right?

Mr. WICHERT. Yes, about 550,000.

Senator REID. See, that's small. With the tremendous problems we have in this country, we are basically not doing much.

Mr. Noland, how might the aerospace-defense industry best contribute to the development of renewable energy systems and hydrogen research and development for commercial use by the public?

Mr. NOLAND. The American people have spent a great deal of money investing in the defense-aerospace industry over the past four decades. That investment has resulted in a variety of technologies for space application. We've mentioned frequently some of the high energy density storage systems that have been developed for space applications. Some of that technology can and should be transitioned into the commercial sector and I believe we can participate in that effort.

I think there is an even bigger benefit from the investment that the American taxpayer has made in the defense aerospace industry and that's primary in the defense-aerospace worker. These men and women, the scientists, the engineers, their support people, who are available now that the Cold War has subsided, can turn some of their attentions, not all, but some of their attentions toward the emerging strategic national problems of the 21st century.

I believe that is where the defense-aerospace community can really apply its best talent; that is, to take these scientific personnel and allow them to apply their systems approach, the discipline, the rigor that approach requires, to solve problems of clean, renewable energy and a variety of other problems that we face in the 21st century. Additional problems might include waste management, problems of renewable energy, what have you.

That, Senator, is where I believe the defense-aerospace community can make its greatest impact.

Senator REID. We're going to do something in this committee at a subsequent time on solar but what your company has done in solar is certainly excellent and it's too bad you didn't get more help from the government in the work that you did during the 1980s on that Stirling dish that Senator Harkin has been so involved and interested in, Stirling technology. Lockheed put it into force in your solar collectors. It's too bad we didn't go further in that in helping you.

Mr. Bates, I want you to report back to Ford Motor Company that we're really happy that you participated in these hearings and they sent you, a graduate of MIT, someone that's involved in the development of new technologies with Ford Motor Company. I say that because it's obvious to me that if this is how Ford reacts to other new technologies, that must be why you're selling the number one car in America today. Based on how I've been treated by the other companies in participating in this hearing, I should be driving a Ford and I'm not. [Laughter.]

You report back that we appreciate Ford's cooperation in this. While I don't agree with all your testimony, I really do appreciate Ford being willing to come forward. The other motor companies were not responsive, they simply didn't want to participate. One of them said so in writing and the other said so on the telephone. so we appreciate your being here.

Mr. BATES. I'd be happy to work with you.

Senator REID. The one area that I disagree with your testimony is that I think that you are not giving hydrogen enough credibility, for lack of a better word. You say hydrogen is fine—I'm paraphrasing what you say—and you say that it may have a role as a transportation fuel, but there's problems.

Is the reason that you kind of lowball hydrogen because Ford has invested so much in battery technology?

Mr. BATES. Not at all, sir. It's just an issue of an awful lot of steps to be overcome before we can see hydrogen as viable, there is a lot of effort ahead of us in order to do that.

Senator REID. I would ask you to return also to your corporate management and have them again take a close look at this because, as you've suggested in your testimony, we're moving at "a reasonable pace," in pursuing the development of hydrogen-related technologies. I think that simply is not valid based upon the testimony that we received from Mr. Lents, that he searched around for somebody to do a joint venture with the South Coast Air Quality District and he had to go to Canada to do that.

The fact that we're relying on a fuel cell developed by Ballard Power Systems of Canada and Fuji Electric of Japan in two of our experimental bus programs in this country certainly does not validate your conclusion in that regard.

This does not in any way suggest from me that your work in electric vehicles is not very important. We commend and applaud Ford for being far-sighted in that regard. I think it's important that we continue with our experimentation regarding electric vehicles.

I was just corrected, it was McDonnell Douglas that did the Stirling dish, not Lockheed, but you take credit. You were involved in it. [Laughter.]

Mr. NOLAND. I figured I'd let that one go by, Senator. Thank you.

Senator REID. Senator Harkin.

Senator HARKIN. Thank you, Mr. Chairman.

I will pick up on that. Mr. Noland, I think you hit the nail on the head when you talked about the fact that we are doing some conversion obviously, and depending on what happens in the world community over the next few years, even more conversion from strictly defense-oriented to more domestic-oriented technologies. This is one area in which we can put a lot of the bright engineers, scientists, some of the best workers we have in America who worked for the defense industry, and move them into an area of renewable fuel technologies that again answers one of our pressing national security needs. I think the security of this country demands in the future that we do that.

I see this as an excellent way of using the defense industry to accomplish two things. First of all, it would utilize the tremendous capabilities of the defense industry with the knowledge and the skills we have in the workers there to help us become more energy independent but it would also keep the skill level up in these technologies and would keep the people in areas where, let's face it, we live in an uncertain world, but if certain forces are unleashed in the world that demand that we move rapidly back to more of an emphasis on military matters, they are there, they are in place. They are not out driving cabs and flipping hamburgers.

I think we should look upon this as part of our national security. That's why, Mr. Chairman, I've said before that a lot of the money that we find now in the defense budget ought to be moved in this direction. Use the existing defense structure that we have, use the private sector that's involved in the defense industry. Lockheed, McDonnell Douglas, General Dynamics, just to name some of the aircraft manufacturers and there are others that could be used too.

I think you put your finger on a very key way that the Federal Government can get involved in this and still maintain a defense posture that will enable us to respond to possible scenarios that may happen in the future. Hopefully, it won't happen but you never know. So I'm glad you said that.

Secondly, Lockheed was involved in OTEC for a long time.

Mr. NOLAND. Yes, sir.

Senator HARKIN. I happen to have visited the OTEC facility off the coast of Hawaii once. I don't remember how many years ago that was but it was quite a few years.

Mr. NOLAND. Probably about 12.

Senator HARKIN. I'd say at least that. I'm just wondering, it didn't seem that OTEC ever really proved to be much for the generation of electricity as such to feed into power grids, but how about it as a possible source of the needed power for making hydrogen?

Mr. NOLAND. Well, Senator, back to your earlier statements about defense conversion, let me just add that fuel cells and fuel cell electric vehicles are in fact on the list of the dual use technologies under the Defense Conversion Reinvestment Transition Act of 1992. We applaud that, we recognize that as a visionary inclusion on that list.

As far as OTEC goes, Ocean Thermal Energy Conversion for those people in the audience who are not that familiar with the term, is a technology that uses temperature differences existing in the ocean to produce electricity via the Carnot Cycle and uses a working fluid, typically ammonia or some other kind of working fluid.

The plant that you visited at Kelaholi Point in Hawaii was a very small demonstration program plant that Lockheed was instrumental in putting together. We put a great deal of our own money into it. I'm told there was an investment by Lockheed of about $8 million in that program over the course of its lifetime, in addition to monies from a variety of other companies as well. Unfortunately, I can't think of all of them, so I won't mention them but primarily small facilities, in addition to the State of Hawaii which was most cooperative in that endeavor.

OTEC itself, depending upon where you locate it, could in fact be a source of electricity to a power grid. In fact, some of those studies are going on now. At the same time, most of the OTEC plants that we have looked at in the past, particularly the large plants, would require the energy produced by the plant be converted to some energy carrier for transportation to shore. We believe hydrogen represents the best choice for that conversion and transportation process. In fact, that's one of the reasons why we're interested in hydrogen in the first place, in addition to the space applications that we've had experience with in the past.

So we view hydrogen as an energy carrier. Our analysis suggests that with a sufficiently large plant, that is, a plant well above 100 megawatts, we believe it could become economically feasible in the future to produce hydrogen offshore and ship it to shore.

One of the elements that makes that particularly attractive is that most of our metropolitan areas which suffer from automobile produced pollution are predominantly in coastal areas, the large majority of them are coastal. So if you're making hydrogen offshore and shipping it to shore, your customers are in fact very near to where you're landing the material.

We hope to pursue that with a great deal more vigor if the opportunity presents itself in an infrastructure mode.

Senator HARKIN. I'd be interested in following it since I've been involved in OTEC in the past. I had not thought about it at that time as a hydrogen producer, more as tapping into an electric grid and providing electricity.

Mr. NOLAND. One of the other energy carriers could be ammonia. We've looked at that as well, NH3. There again, one would ship the ammonia ashore, strip off the hydrogen and use the ammonia in some type of fertilizer activity. That's a way of carrying the hydrogen itself. We, however, believe with some recent advances that carrying high pressure cold hydrogen is a preferred way to go.

Senator HARKIN. Mr. Bates, I also want to join with the Chairman in thanking you for being here and Ford Motor Company's involvement in this hearing. I also want to join with him in saying that I wish that one sentence of yours where you said that "Hydrogen may have a role as a transportation fuel," was a little bit stronger. I guess I'd ask you, for the record, do you think it should have a role?

Mr. BATES. Certainly, yes.

Senator HARKIN. Again, the timing for this is expected to be well into the next century. I fully understand the economic problems the automobile companies have in America today. Obviously, I understand you have to be concerned about this year, next year, short term returns to your shareholders. I understand that, but that's why I would hope there would be more of an indication that the Ford Motor Company, since you're here, would be interested in joining in some kind of joint ventures on this.

If DOE provides the research and development support, would Ford agree to some form of a joint development project, say a 50–50 joint development project to develop direct hydrogen fuel cell vehicles?

Mr. BATES. Certainly we are anxious to participate in that sort of research and will be participating in some of the work DOE has going on. There is actually a CBD announcement that suggests they'd like to have the automobile manufacturers participate in an effort to develop a hydrogen fueled propulsion system and we plan to participate.

Senator HARKIN. That's good news. We had some experience in the past where we have worked with some of the aerospace industries back in the 1970s to develop certain engines, this new super quiet jet engine that we invested some money in and arrangements where that money was eventually paid back. Actually, the Government made some money on it because of the arrangement that was made. I won't mention the manufacturer. I forget right now and I don't want to mention the wrong one, but everyone benefited from it.

Perhaps you might be looking at that type of arrangement with Ford Motor Company where there would be some type of joint development where taxpayers' money would be used up front but with some kind of arrangement whereby if—obviously this is an if—Ford Motor Company made money on it in the future, they would pay the money back.

Mr. BATES. We'd be happy to consider any proposal anyone would like to make.

Senator REID. We've done that in the past and I think that's the kind of arrangement the taxpayers in this country would be looking at too.

Mr. NOLAND. Could I add something, Senator?

Senator HARKIN. Sure.

Mr. NOLAND. For our part, we would be eager to participate and support an effort similar to that, but let me add quickly, however, that the 50 percent cost-sharing is somewhat of a hurdle that the defense industry faces with respect to trying to use the Defense Conversion Investment monies. Not that cost-sharing is a bad idea, but from a corporate viewpoint, a 50 percent share for an investment where the payback term may be in the 7 to 10 year time frame is somewhat of a hardship for industry. So we would welcome the opportunity to explore alternative types of financing efforts.

The President and Vice President in their recent article used the term "patient financing," and that's a very good term. We would welcome the opportunity to use long-term capital so that we could participate in long-range development efforts without burdening the shareholders of the company with long-term financing.

Senator HARKIN. I'd worked on getting a provision in the 1990 farm bill that's called the "Alternative Agricultural Research Demonstration and Commercialization Act." We've now put a little bit of money into that, we're moving ahead but the law stipulates that we could use a variety of different financing mechanisms jointly with small companies—some of them are pretty small—to develop and commercialize certain alternative products.

One of the methods we used that's finding some favor out there is some form of a convertible debenture, for example, that we've reached with some of these companies. They seem to enjoy that kind of a process. So there's a lot of different financing mechanisms that can be used—maybe an equity position or something like that.

Mr. NOLAND. We've got enough intelligence in our finance community that we ought to be able to come up with something that everybody can live with.

Senator HARKIN. I think so too.

I didn't read the article on SMUD until you handed it to me. That's pretty interesting. You had this one thing in your testimony, Mr. Wichert, sort of a statement of the different approaches, the project types, and how much you were asking for in an annual Federal budget. What you're pointing out is that with a $150 million annual Federal budget in these areas, you talk about creating over 4800 private sector jobs.

Mr. WICHERT. That's correct. Those are examples of integrated projects which might lead towards fuel cell, renewable, solar, hydrogen fuel cell vehicles and power plants.

Senator HARKIN. Are you looking at that bus up in Canada?

Mr. WICHERT. Yes, we are. We're investigating it. We honestly would prefer to participate in an extension of the DOE program in this country, but obviously they put theirs out first.

Senator HARKIN. Are you going to make any hydrogen at that 2 megawatt plant of yours?

Mr. WICHERT. That plant just feeds into our electrical grid. We do use some of that electricity to charge battery electric vehicles but we plan to put in a purpose-built 200 kilowatt photovoltaic array to make hydrogen.

Senator HARKIN. Aren't there some times though when your 2 megawatt is making electricity you don't need? You're using that now to generate and recharge batteries?

Mr. WICHERT. Yes, we are. We could use some of that to make hydrogen but we prefer to make it an integrated project that has a purpose-build 200 KW photovoltaic system to supply the fuel for the bus.

Senator HARKIN. Have you tried to get any kind of DOE funding for your solar hydrogen bus?

Mr. WICHERT. We are attempting to pursue the Advanced Research Project Agency funding that should be out soon. We're also looking at some of the section 2026 funding that we hope will be available in the following year.

Senator HARKIN. Thank you.

Thank you, Mr. Chairman.

Senator REID. I appreciate very much the testimony of all of you. This has been most helpful to have you each here with your own niche and we look forward to working with you as time goes on.

Thank you very much.

Our final panel today will consist of Mr. G. Neal Richter, a Research Fellow with Texaco; Mr. Willard Olson, Vice President-General Manager, McDonnell-Douglas. Mr. Olson, let me now give you credit for the Stirling dish solar collectors that I viewed in the rain in southern California.

Mr. OLSON. We're willing to share.

Senator REID. We were fortunate in that the rain did break and I was able to get out and look at them, and feel them. I appreciate that and I'm sorry I mentioned that in line with Lockheed.

Mr. Pat Ryan is also going to testify today. He is with Atlantic Richfield out of Los Angeles, California.

The first witness will be Mr. Richter, then Mr. Olson and then Mr. Ryan.

STATEMENT OF G. NEAL RICHTER, RESEARCH FELLOW, TEXACO'S MONTEBELLO RESEARCH LABORATORY

Mr. RICHTER. Good afternoon and thank you, Senator Reid, for this opportunity to testify before you and the other members of the Subcommittee on Toxic Substances and Research and Development.

We greatly appreciate the opportunity to contribute to this discussion on the current state of environmental technologies related to the development of renewable energy sources, specifically in the hydrogen energy sector.

In addition to the things I've got, I'd point out one other problem we have that came up yesterday. On my airplane flight, I told the person next to me that I was going to be testifying on hydrogen and the answer was, "bombs or peroxide"? I think we have a great deal to do to let people understand what we're trying to do with this hydrogen fuel business. [Laughter.]

I'd also like to use this opportunity to share with the subcommittee some of the broader applications of Texaco's gasification technology. While it's been primarily based on fossil fuels, today we are looking in new directions including the beneficial reuse of industrial and consumer waste.

Texaco is the only major oil company that's maintained an Alternate Energy Department through the 1970s, 1980s, and now into the 1990s. We believe we're uniquely qualified to speak to the production of high purity hydrogen because of the worldwide successful commercial use of the Texaco gasification process. For the production of hydrogen and other products, this process has been used for over 40 years.

Currently, there are 47 commercial units either operating or under construction which will have a total capacity of over 2.2 billion standard cubic feet of synthesis gas, hydrogen and carbon monoxide, which are in many ways equivalent.

We see the U.S. demand for hydrogen increasing dramatically over the next decade in a number of areas. While the existing hydrogen supply is expected to drop. The Clean Air Act amendments of 1990 require refiners to lower their aromatics in gasoline which results in less hydrogen being produced in refineries and at the same time, we need additional hydrogen to clean up the other fuels they are currently producing. The additional hydrogen capacity, we estimate, could exceed 4 billion standard cubic feet per day over the next 10 years.

Texaco has recently enhanced its gasification process to produce high purity hydrogen through a U.S. patented process called HyTEX. This proprietary process is designed to produce high pressure, high purity hydrogen from gaseous refining waste streams in an environmentally superior and economically competitive way.

The HyTEX process is environmentally superior to the alternative processes available today, such as steam methane reforming, in two particular ways. First, it has virtually no NO_x emissions because it does not have a large furnace with extensive stack emissions. Second, because of its feedstock flexibility, it can use assorted gaseous liquid and solid waste materials in the process, we are contributing to the reduction of waste streams, converting them to something which is an attractive, useful product. In all this, we now believe we are perhaps economically competitive, or superior, to other hydrogen general processes.

Actually, these wastes can be used in any use of the Texaco process to make products besides refinery hydrogen, hydrogen for other purposes, as a feedstock for making ammonia, for generation of electricity, for production of heat and many other chemicals.

We have demonstrated at both our Montebellow Research Laboratory and in commercial projects that due to the extremely high temperature of the process, virtually any organic material is destroyed. This is in combination with the technology's ability to encapsulate or trap any metals, and trace components in a nonleachable form, provides us with a method to destroy waste which is superior to incineration and other forms normally being used. Our ability to use waste streams could result in significant reduction of waste disposal.

In addition to our current commercial activities, the things we've been doing in the past, and waste gasification, we're looking at other future uses of hydrogen. Texaco's gasification process has been closely followed by various agencies and national laboratories. We are presently discussing research projects with some of these agencies which address many of the matters discussed here today.

In pursuing these objectives, we've discovered that one of the major barriers hampering development of new environmental technologies such as ours seems to be the manner in which some of the regulations and procedures are managed. We've experienced enormous delays in obtaining permits or variances to perform tests that are needed for development, and had problems in dealing with different agencies, getting one to look at someone else's problems.

I would like to just point out that I think the South Coast Air Quality Management District is one which has been very cooperative and has been easier to deal with than many others. It's not that we're not trying to meet the regulations or want any respite from the regulations, it's just that we need to be able to get to a conclusion somehow and get on with our work.

In addition to just doing technical work, we also have to make sure that we can do these things economically. One particular problem is that in many cases to benefit from the economies of large scale in generating hydrogen, we have to do this in combination with production of some other products, often electric power. However, many public utility commissions I think have a discrete agenda that does not encourage a broader societal view. If we can get better integration of these environmental economic advantages, we believe we could advance our technology more rapidly.

Thank you again for the opportunity to address the subcommittee. It's been an honor for me to appear before you today and I'd be pleased to address any questions you may have.

Senator REID. Mr. Olsen.

STATEMENT OF WILLARD P. OLSON, VICE PRESIDENT-GENERAL MANAGER, McDONNELL-DOUGLAS AEROSPACE, HUNTSVILLE DIVISION

Mr. OLSON. Mr. Chairman and Senator Harkin, thank you for allowing us to be here today. It's a privilege for McDonnell-Douglas to represent our corporation here.

Let me first say that I'm in charge of our operations in Huntsville, Alabama but the things that I have to talk about really went on some years ago in California. So you might add us to the list of all the other California people that are here.

As you know, McDonnell-Douglas is the Nation's largest defense contractor right now. We are also the second largest supplier to NASA, and the third largest developer of commercial aircraft in the world. The list goes on like that, but among those things, we also from time to time take on different projects. Back in the mid-1970s to mid-1980s, we found ourselves working on many kinds of renewable energy programs. In particular, I'd like to talk about three programs, two renewable energy programs and one other program that's ongoing, and has been ongoing in our corporation for several decades.

First of all, you're aware of what was called Solar I out in Barstow. We were the system design integrator for that and that was a 10 megawatt electric power system that was put on something like 100 acres of land and had about 1800 heliostats, which are large tracking flat plate mirrors. After we had worked on that in the early 1980's, we decided there were several things that could be improved upon with that system. One, it wasn't modular, since you had to have all the mirrors shining on a tower that heated water and produced steam for turbines and that was what ultimately gave you your electrical power. Also, we didn't think the efficiency was as high as it should be.

We entered, at that time, into a working agreement with a company in Sweden, United Stirling-AB and we produced our Dish Stirling power sources. We built eight of those and they are at various locations in this country and Japan. They've been operational for 9 years. We believe that they have the highest total system efficiency in the world today. For any solar energy systems I'd point out also that although we got out of the business, in the mid-1980s, those Dish Stirling engines have been working with the parabolic mirror collectors that you saw, Senator, at our company out in California during this entire period.

The point of all that I'll get to in a minute is that we had to get in and get out of some of the renewable energy business as dictated by the marketplace and also as dictated by, if you will, Federal policy and budget. The company did spend several tens of millions of dollars of its own money on the Dish Stirling Solar Energy System.

The third thing I wanted to talk about very briefly is not really a program or a project but just the fact that we have, in our company and in aerospace generally, been dealing with hydrogen fuels for several decades. As such, we've used them to fuel the Saturn IV that got us to the moon and back; the Shuttle uses liquid hydrogen and liquid oxygen, so we're quite used to using that. We really have existing an infrastructure for using liquid hydrogen and liquid oxygen, and some other exotic fuels, as well as cryogens.

Because of our work on the national aerospace plane, we also developed a capability for working with slush hydrogen. Slush is like a "slurpee." The reason for looking at a mixture of liquid hydrogen and its crystalline ice is the volumetric content of energy in it is a lot higher than just liquid hydrogen. We have transported it, we have stored it, and transferred it. We have also developed composite tanks, by the way, to store both slush hydrogen and liquid hydrogen and these tanks don't leak. The point being that the aerospace industry has made some advances not so much in hydrogen fuels for use in the automobile or without thinking of a hydrogen economy, but there is already an aerospace community experience base with a lot of information and a lot of capability in some of the things we've been talking about here today.

The message that I'd like to leave with you is that getting in and out of the Dish Stirling business and the solar power business in general was in large part due to Federal policy shifts. We would welcome some kind of a long-term Federal policy that would encourage development of a hydrogen economy, alternate energy sources and also deal with the transition of aerospace workers into these fields.

My colleague from Lockheed mentioned that there is a problem, as you know, in our industry right now. We would like to use that resource as well as we can to apply it to the problems that the Nation finds of interest and needs to solve in the next years.

The last point I'd like to make was underscored also by a previous speaker and that is we need to score a touchdown with a hydrogen economy and it can't be done with just the R&D. You need to look at units, you need to look at going from the R&D to power plants and entire systems, looking at all of the different steps that need to be taken before it actually becomes part of our consumers economy.

I look forward to the relationship with industry and the Federal Government as all that takes place.

That concludes my comments.

Senator REID. Mr. Ryan.

STATEMENT OF PATRICK W. RYAN, CORPORATE CONSULTANT, ATLANTIC RICHFIELD CO.

Mr. RYAN. Thank you, Senator Reid and Senator Harkin, and the subcommittee for inviting me here to testify on behalf of ARCO.

Concerning my position, I'm a consultant to executive management at ARCO and I'm responsible for monitoring new and emerging technologies. Over the past one or two years, I have focused my efforts in the area of alternate fuels and alternate fuel technology.

ARCO has been involved in alternate fuels for quite a while now. They were the first company to introduce environmental gasoline in the State of California into the marketplace. More recently, we've refocused some of our studies to looking at the whole area of alternate fuels and these studies were really aimed at trying to come up with what are the best transition fuels in the future and what in the future will be the transportation fuel.

In order to do that, if you have Figure 1 from my written testimony in front of you, look at that. The main transportation fuel today is gasoline which powers over 90 percent of our fuels. The alternate transportation fuels that we have under study included the alcohol fuels—methanol, ethanol, compressed natural gas, reformulated gasoline, electric battery-powered vehicles, and hydrogen. We wanted to see what was going to make the next cut and be the final choice.

We rank these fuels in terms of cost, energy efficiency, energy security, environmental factors, technology constraints and infrastructure issues. That ranking summary is shown in Figure 2 of my written testimony. You might want to refer to that.

If you go to the ranking summary and you look across there, what we tried to do is the lower numbers here were a better ranking. So we looked at cost, energy efficiency, security, and so on and gave these an equal weight on a ranking. I just added up the overall rankings and came out with some numbers.

What it shows is that if you have a motor fuel today, the best motor fuel you can have, adding across all of these factors, turns out to be reformulated gasoline. However, if your drive is for a fuel which is totally energy efficient, has the best security characteristics, and the best environmental comparisons or environmental characteristics, then your choice clearly becomes electric vehicles and hydrogen-powered vehicles.

CNG came out a little bit worse than reformulated gasoline and the alcohol fuels did not come out too well at all. They were probably the lowest ranking. Electric and hydrogen came out close to reformulated gasoline. Electric did at 11 and hydrogen a little bit worse. Hydrogen and electricity, the main message here is that from an energy efficient standpoint, a security standpoint, or environmental comparison, they look like the best fuels.

For the electric and hydrogen to become viable, costs must be improved, infrastructure issues must be addressed, and technology constraints must be overcome. In terms of compressed gas and natural gas, we feel that can build a niche role in the future and that can be an excellent fuel for fleet vehicles and that would be its role.

The best use for alcohols that we can see in the transportation fuels that use methanol or ethanol in terms of making oxygenates, MTBE and ETBE in reformulated gasoline. If you accept that, this would lead you to a strategy that one, making investments or encouraging investments in reformulated gasoline, because that is the transition fuel that should be used until you get to electric vehicles and hydrogen-powered vehicles. So you ought to be encouraging investments for oil companies in reforming gasoline.

You should be making investments in niche markets which would promote electric vehicles. Here, I will include battery work, infrastructure programs, et cetera, programs in hydrogen generation technologies, including solar hydrogen systems, the Solar GENSA looks like it has a lot of potential. You ought to be encouraging investments in fuel cell programs and you ought to be encouraging investments in infrastructure programs for electric vehicles and hydrogen fuel systems.

The other thing I would recommend is that we ought to be deemphasizing work in the alcohol fuels. I don't think it makes a lot of sense to carry along four or five different fuels as transition fuels if the future is really hydrogen and electric vehicles. I think we ought to deemphasize what's going on in alcohols and use that money in the R&D programs for EVs and hydrogen. That scenario is really pictured in my last figure which shows fuels making cut two should be compressed natural gas for niche markets, reformulated gasoline transition fuel into the future, and electric and hydrogen with the future being a combination or reformulated gasoline, electric vehicles, and hydrogen-powered vehicles.

Thank you.

Senator REID. I think this says something about the state of the desire of our country to change from fossil fuels and that's indicated by the fact that we have here today representatives of Texaco and representatives of Atlantic Richfield. Both of your companies are to be complimented.

Mr. Richter, I am impressed with the three decades of research that your company has done. Could you tell me a little bit about your Montebello facility, what it is, and how many people are involved in it?

Mr. RICHTER. Sure. That's the place where I am. It is relatively small. Right now, we have 85 technical employees and really, we have three small scale gasifiers, and all their supporting equipment. It's been there since 1945, all this time, working on gasification, starting with natural gas and coal and proceeding now through all kinds of petroleum up to waste products.

What we do is find out how to gasify each one of these materials, do the work to make them commercial, get the data to build plants, to support the environmental work to permit plants, and then we'll help train people from commercial installations.

Senator REID. Tell me what you mean in your statement on page three, "We see the U.S. demand for hydrogen increasing dramatically over the next decade, while the existing hydrogen supply is expected to drop."

Mr. RICHTER. Looking specifically at the refining business, under the Clean Air Act of 1990, aromatics have to be reduced. Currently, most of the hydrogen that refineries generate is done internally making aromatic compounds of the particular type used in gasoline. If you take that out of gasoline and no longer make them, you no longer make the hydrogen. So they're losing their supply of hydrogen and at the same time you're trying to make everything cleaner by taking more sulfur and more nitrogen compounds out and these things require hydrogen. So there is a great squeeze coming on all of the refineries at the current time looking at making some of the reformulated gasolines.

Senator REID. That squeeze is right now?

Mr. RICHTER. It is starting right now, it is going to hit in 1995 regulations?

Senator HARKIN. 1996.

Mr. RICHTER. 1996. We are very actively working with a number of people trying to develop projects ourselves either in a joint venture to supply hydrogen or by licensing.

Senator REID. Would you also explain the statement on page four of your written testimony, "Texaco has recently enhanced its gasification process to produce high purity hydrogen to meet this demand in a more economical manner by incorporating the latest industrial purification technology"?

Mr. RICHTER. When you produce hydrogen, you not only have to convert the material to a gas, hydrogen and carbon monoxide, then you have to remove the other components besides the hydrogen from it. There has been a new development in how to remove other components from the gas so that you have only a high purity hydrogen. This change has made a 20 or 30 percent reduction in the overall cost of hydrogen made by our process. So it's been a combination of several different new technologies into our process to make it better.

Senator REID. Mr. Richter, along with making strides in the gasification process, and you've been working on that for almost 50 years, has Texaco been looking at delivery systems?

Mr. RICHTER. We have been looking at industrial commercial hydrogen, large scale hydrogen for refineries, ammonia plants, various synthetical chemical plants. We have not, up to now, gotten into looking at other distribution or infrastructure for any other end use of hydrogen ourselves, no.

Senator REID. I would like all of you to respond to this question. I think, Mr. Olson, you've already done it but I'd like you to respond again. Part of the problem for Texaco, ARCO, and McDonnell-Douglas is that I think you're reluctant to invest in renewable energy research and development such as hydrogen because you're not sure what the Government is going to do from year to year. We know what happened with solar. Is that a fair statement, that corporate America is unwilling to do any long-range research and development realizing the Federal Government doesn't know from year-to-year what they're going to do and you compare that to the testimony we've heard here today where the Japanese government is entering into a 27-year program.

If we came in here today and said, you have a quarter of a century of support from the Federal Government because here is where we want to go, that would help, would it not?

Mr. RICHTER. Obviously.

Mr. OLSON. I think industry, each public company, will do what it has to do, to maintain the products that it already has. That's kind of its first obligation. To look into new marketplaces is always difficult and I think the experience that we had 10 or 15 years ago tells us that. Part of reason the marketplace is up because of the changing Federal policy.

If we had some kind of a long-term Federal policy enunciated, I believe you'd attract a lot more interest from industry in taking it from the existing products they have and trying to get some new product lines.

Mr. RYAN. I think you need a fixed strategy here in Washington. It's very confusing in the alternate fuels area. There are certain legislators who are going to be pushing ethanol, certain people are pushing methanol, certain people are pushing compressed natural gas, without anybody really sitting together and trying to figure out, if these fuels are going to be transitional, shouldn't we zero in on one of these and quit being wasteful, spending money on trying to develop them all. This company is capital-constrained. I don't think it makes a lot of economic sense to develop all those fuels, so if we focus in and say, this is going to be our transition fuel, these are going to be the final choices—electric and hydrogen and those two technologies complement one another—then we have a strategy where we can set an investment policy.

Mr. RICHTER. I certainly agree that we don't have enough resources and capital, we don't have enough resources of people to pursue many different directions and if you go in one direction and have something change on you, you can have your whole company committed in the wrong place. We do have to have better policies or firmer policies. We have to understand where we're going. This would help us all.

Senator REID. Really a good example, and I hate to keep harping on this, is the experience of McDonnell-Douglas in regard to your solar energy quest. You, in effect, had the rug pulled right out from under you when we suddenly had an oil glut and the tax incentives and other programs we had in the Federal Government to help develop alternate fuel sources just stopped. Oil shale is a good example. Companies invested huge amounts of money in oil shale research and development and then no longer got support from the Federal Government.

I'm not a scientist but I understand that we have the need to get away from fossil fuels and we also have a huge source in the sun that is in effect wasted every day in the deserts of Nevada and other places that we're going to have to use. It's only a question of time until we start using solar energy for development of hydrogen and other types of fuel. Would anyone disagree with that statement?

Mr. RICHTER. It's very clean energy fuel. Hydrogen in conjunction with fuel cells is a nice way to look at it.

Senator REID. Thank you.

Mr. Olson, the amount of money that McDonnell-Douglas put into Dish Stirling solar technology is significant, in the tens of millions of dollars. Do you know what the stage is of Dish Stirling technology today? As I indicated in an earlier question to a witness, if 100 percent is perfect, do you think when you stopped this you were at the 20 percent level, 30 percent? Where were you?

Mr. OLSON. When we stopped it, we sold some of our Dish Stirling receivers to several places and they have been operated since the time back in the 1980s that we had to quit working on it. So we do have the advantage of information on the operation of those receivers for a 8 or 9 year period. I did state earlier that they are probably the best system efficiency of any kind of heat engine that's been used to convert from solar to electric.

I haven't given you a number but I think it is an existing technology. I don't want to say it's only 10 percent of where it needs to go. You could take the equipment that we used and you could use it to produce electric power. The question, of course, is the cost. That's what needs to still be done, how much per kilowatt hour.

Senator REID. One of the objections that we continually get to solar energy is it takes so much space, but those people that make that statement probably haven't been to Nevada. We have a huge State, seventh largest State in the Nation, of which, 87 percent is owned by the Federal Government. We have huge military installations that have been there for a number of years that are being cut back. The Nevada Test Site is going to end after three years, a multibillion dollar infrastructure there. So space is not a problem in Nevada. You can take up a lot of the space in the State of Nevada and we wouldn't miss it.

Mr. OLSON. May I comment?

Senator REID. Yes.

Mr. OLSON. Each of the Dish Stirling receivers that we talked about that we built just about a decade ago produces 25 kilowatts of electric power. That's enough, I believe, to serve the needs of a few families. The receiver sits on about a fifth of an acre of land, so you're talking about less than a tenth of an acre of land per family if you're using solar energy to produce electrical.

Senator REID. I think Mr. Olson, it's less than that.

Mr. OLSON. I believe it is. It's less than a tenth.

Senator REID. I'd like at this stage of the record to read something out of your written testimony, Mr. Olson.

> We recommend that an agency of the United States Government take the lead to revitalize research and development in these technologies at a rapid pace with one objective being the demonstration of the Dish Stirling Concept as a supplemental source of low cost, nonpolluting electrical power within the next few years.
>
> In parallel, this agency should support the development and demonstration of hydrogen as a transportation fuel, together with a ground infrastructure that would make distribution of this fuel practical at the consumer level.
>
> Finally, this agency should implement a pilot project that would allow demonstration of solar power generation, water electrolysis, hydrogen storage systems as well as distribution systems in operating vehicles.

That is what this hearing is all about today. We really need the Federal Government to become more assertive and more of a leader and be an organization that is setting the future of this country rather than reacting to what's going on in the private sector and around the world.

Each of you, I appreciate you and your companies sending you here today. You've made the hearing most meaningful and I appreciate your testimony and look forward to working with you in the years to come. Thank you very much.

Today, there will be a demonstration of a hydrogen-powered vehicle. The vehicle is a Dodge pickup truck with an internal combustion engine that is powered by a fuel injection system that relies on hydrogen as its fuel source. This small size pickup truck is sponsored by the Clean Air Now Coalition of Riverside, California. The pickup has been used in demonstrations and of course poses no safety threat.

This demonstration will take place at the Capitol Plaza area. I've asked the sponsors of the vehicle to have the vehicle available at that location from 12:30 p.m. until 2:30 p.m. today.

I'll continue to work diligently in this committee to take whatever steps are necessary to set the course that will lead us in the direction of new energy and environmental future for this country. There is no doubt that this is the first in a series of hearings this subcommittee will hold, has held now. We're going to look into other technologies to bolster the hydrogen fuel concept by looking next at a hearing on solar energy.

Thank you very much.

This committee stands in recess.

[Whereupon, at 12:40 p.m., the subcommittee was recessed, to reconvene at the call of the Chair.]

[Statements submitted for the record follow:]

Statement of Honorable John H. Gibbons, Director
Office of Science and Technology Policy

Mr. Chairman, Members of the Committee, thank you for the opportunity to speak with you today about the growing promise of renewable energy sources. Given adequate support, renewable energy could provide half of the energy needed by the world economy by the middle of the next century. Large-scale use of renewable energy is essential if we are to maintain rapid worldwide economic growth without increasing global production of pollutants. Cost-effective renewable sources of electricity and fuels can provide much needed diversity of energy supplies in all parts of the United States -- diversity that can mean continued competition with conventional fuel sources that will help ensure stable prices.

My testimony will begin with a brief overview of the status of renewable energy. I will then discuss a plan announced by President Clinton on February 22, 1993, to work closely with the automobile industry to encourage exploration of new propulsion systems and new domestic fuels, particularly domestically produced renewable fuels.

Renewable Energy Sources

The term "renewables" includes a wide range of energy resources that appear, for example, as sunlight, wind, falling water, biomass, and heat in the earth's crust. These energy forms have been used for centuries, but a variety of technologies -- many demonstrated only in the past few years -- can now be used to convert these resources into economic sources of fuel and electricity for a modern society. Many of the needed technical advances have come from unexpected sources, such as aircraft engines, advances in semiconductor physics, and advances in biochemistry.

Sunlight can be used to heat fluids to operate electric generating turbines; and it can also be converted directly to electricity using photovoltaic cells. We've always used sunlight to grow plants for food and fuel and advanced technology can convert biological materials -- including waste paper and other materials -- to sources of gaseous, liquid, and solid fuel for electric generating turbines. Advanced gasifiers and turbines now in advanced design stages should be able to produce electricity from biological materials at prices comparable to that of electricity derived from coal. Improvements in the cost and performance of photovoltaic cells means that these devices already provide attractive sources of electricity in specialized applications. Applications can be expected to grow rapidly as costs are further reduced. Advances in wind machines, made possible by a decade of continuous technical development and field experience in California and other locations, has driven the cost of wind power down to a point where wind is competitive with conventional forms of electric generation today in select locations.

Renewable energy can also be used as a source of liquid and gaseous fuel for operating vehicles. Waste materials and rapidly growing energy crops can be converted into alcohol fuels and used as a direct substitute for gasoline.

In the longer term, hydrogen may provide an attractive way of transporting and storing renewable energy -- particularly if hydrogen is used in highly efficient fuel cells. Hydrogen can be made from natural gas, from biological materials (including waste materials), and it can be manufactured from electricity. Measured in terms of dollars per unit of energy content, alcohol and hydrogen fuels are likely to be more expensive than gasoline well into the 21st century. But the true value of these fuels must be measured in terms of full cost per mile driven. Given time and adequate investment in research, the life-cycle combined cost of owning and operating an automobile using an advanced propulsion system with renewable energy sources can be comparable to that of today's gasoline-powered vehicles using internal combustion engines.

None of the economic comparisons I've referred to here give renewable resources credit for other benefits not captured in standard economic accounts. For example, production of renewable resources can lead to economic development and employment opportunities, particularly in rural areas. It can lead to land restoration when abandoned or degraded farm lands are managed for sustainable production of biomass. Renewable energy sources generally produce fewer air pollutants and greenhouse gases than conventional, fossil fuels. Renewable resources are diverse, leaving us less dependent on a few energy suppliers. Global development of renewable energy would lessen the attractiveness of nuclear power, thereby reducing the risk of nuclear weapons proliferation and the vexing issue of high-level waste disposal.

The challenges we face in government are: 1) finding a way to provide balanced support for the rich set of technical alternatives in renewable energy by combining public and private research funding; and 2) ensuring that private investors have the incentive to experiment with the alternatives so that winners and losers can be identified in competitive markets.

A Renewable Energy End Use: The Automobile

No industry is more important to national economic recovery than the domestic automobile industry and its suppliers. Motor vehicle production generates nearly one-tenth of all compensation paid to American manufacturing workers. Automotive production touches all parts of the economy -- accounting for one-sixth of the output of the iron and steel industry, and one-eighth of the output of industries ranging from textiles to service machine production.

As a result, we must pay careful attention to technology that can help American producers become the most agile and efficient in the world in the way they design, test, and manufacture vehicles. And we must ensure that U.S. producers take the lead in developing vehicles that can enjoy large domestic and international markets because they are safe, fun to drive, produce little or no pollution, and can operate on domestic fuels -- including renewable fuels. With such a product, automobile manufacturers would make a dramatic contribution to the Nation's environmental, energy, and economic security and their own survival in highly competitive world markets.

Cars and trucks account for about half of the volatile organic compounds and nitrogen oxides and 90 percent of the carbon monoxide dumped into the air of the nation's most polluted cities. Reducing emissions further with tailpipe emission control devices is proving remarkable difficult, and reductions in the emissions of individual vehicles are being offset by the growth in the vehicle fleet. Highway vehicles also account for 25 percent of total carbon dioxide emissions from burning fossil fuels in the United States. The Intergovernmental Panel on Climate Change estimates that to prevent climate change (beyond that to which we are already committed because of past greenhouse gas emissions) would require cutting emissions by 60 percent or more. This cannot be accomplished without radical changes in our fossil fuel-intensive systems of energy production and use, including automobiles.

Automobiles and light trucks now consume over 6.1 million barrels of oil per day -- equivalent to 85 percent of current oil imports -- and are expected to consume 8.2 million barrels per day by 2010. The prospects for achieving energy security by diversifying oil imports is not bright, since the Middle East holds 65 percent of the world's oil reserves. The Middle East could again dominate world markets early in the next Century, and the energy security problem is compounded by the rapidly rising demand for oil in the developing world.

The President's technology initiative, Technology for America's Economic Growth: A New Direction to Build Economic Strength, focuses on supporting applied research in areas where public and private interests intersect. His new program introduces several fundamental innovations in the way the nation will approach applied research and development.

-- For many years, American technology policy consisted largely of mission-oriented research in DoD, NASA, and other organizations coupled with an abiding faith that much of the technology developed for these missions would eventually prove useful to the civilian economy. There have clearly been successful transfers. Our new policy moves carefully, but directly, to support civilian technology using cost-shared research, dual-use defense programs, and a variety of other methods.

-- We established a goal of integrating environmental goals with goals in economic development rather than relegating environmental interests to an afterthought. This is good environmental policy since it reduces the cost of meeting any environmental goal. It is also good economic policy since it minimizes the cost and burden of environmental regulation, lowers production costs by encouraging efficient use of energy and materials, and encourages development of a domestic industry capable of producing products acceptable to broad world markets because of their low emissions.

This new philosophy finds a perfect fit with the needs of the automobile industry. We have an opportunity to connect Federal R&D spending with marketable products and good jobs. We have an opportunity to work with industry to make environmental interests an integral part of technological development rather than a constraint. Both industry and government must examine the way they do business and develop the means to respond rapidly to changing needs and opportunities.

Radical Technological Change

Dramatic action is needed to resolve the energy security and environmental challenges posed by automobiles and to find ways to revitalize the automobile industry. We will be working closely with the automobile industry to design a program of research that not only helps U.S. industry produce the best vehicles in the world but helps them build these vehicles with the world's most efficient manufacturing technologies. We hope to develop a balance program including both projects with a clear, near-term payoff and projects that can lead to fulfillment of ambitious long-term goals. The role of renewable fuels will be considered carefully as we work together to design an effective program.

A wide range of options exist, and we will take great care to design a balanced research portfolio. Many concepts we will be discussing involve major research challenges and may not be ready for market for many years. Some will fall by the wayside as the market sorts the alternatives. It is essential that we create a market-based process that allows technical and economic merit, not the enthusiasm of special interests or bureaucrats, to be the final

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arbiter.

Replacing Gasoline

During the next few decades, several fuels will be competing for markets now dominated by gasoline. In the near term, the most important renewable transportation fuels are likely to be ethanol and methanol used in internal-combustion engine vehicles (ICEVs). Battery powered electric vehicles (BPEVs) may provide practical transportation in many markets. In the longer term, however, methanol and hydrogen used in hybrid vehicles, including fuel cell electric vehicles (FCEV), may be preferred. Hybrid vehicles generate electricity onboard the vehicle from a liquid or gaseous fuel.

Shifting to fuels other than gasoline is an enormous undertaking. We should take care that changes introduced in the next few years are consistent with our long-term goals. For example, natural gas vehicles would give us an opportunity to explore strategies for delivering and storing compressed gases for use on a vehicle. In the longer term, it may be desirable to convert natural gas to hydrogen for use in an FCEV. Somewhat later, hydrogen from renewable sources could be added to the market. With appropriate guidance from industry, we can design a well-balanced program of research, regulation, and federal purchasing that can meet both near-term and long-term objectives.

Ethanol and methanol are alcohol fuels that can be made from any plant material -- including organic material in urban waste, the residues from agriculture and forestry, and plants grown expressly for use as an energy feedstock. While today's production of alcohols is limited to a relatively expensive process using corn as a feedstock, advances in biotechnology now make it possible to use paper, wood-chips, grasses, and other low cost sources of cellulose to produce a competitively priced fuel. While waste materials are likely to make the most attractive sources of biomass in early applications, U.S. farmers can find new uses for idle land by growing crops expressly as an energy source. This additional source of farm income, together with local production of alcohol fuels, could be a major source of economic development in rural America. Farm incomes could increase while public expenditures decline.

Biomass plantations also provide an opportunity for developing nations, particularly those in Africa and South America, to find new uses for degraded lands. While substantial and sustained research will be needed to find ways to restore these lands, there is reason to be optimistic that methods can be developed to produce cash crops in enormous regions in these countries where the lands have been abandoned because of poor agricultural or forestry practices. Sales of biomass crops could help finance the restoration of these lands.

Methanol is produced from biomass via a thermochemical process that begins with the gasification of biomass at high temperature. The products of gasification, including carbon monoxide, hydrogen, and methane, are converted to methanol via well-established industrial processes developed originally for making methanol from natural gas and coal.

Both methanol and ethanol are excellent fuels for use in ICEVs. As liquids, they are easy to store, and their wide use would require only relatively modest changes in the fuel distribution infrastructure. When optimized for operation on alcohol fuels, ICEVs are about 20 percent more energy efficient than when operated on gasoline.

Hydrogen will be an important fuel if the FCEV replaces the ICEV. Hydrogen can be manufactured from natural gas with commercially available technology at a higher efficiency and a lower cost than for making methanol from natural gas. More importantly, hydrogen can be produced from biomass or various waste feedstocks with the same gasification technology that would be used to produce methanol from biomass. Hydrogen can also be produced by splitting water electrolytically, using electricity from renewable sources such as hydroelectric, wind and photovoltaic power. Hydrogen produced from these sources and used in FCEVs could provide transportation with no pollution. Potential supplies of hydrogen from these sources are vast, and the production of hydrogen would make it possible to exploit much more of intermittent sources than would otherwise be possible.

New Propulsion Systems

Large improvements in fuel economy and large reductions in emissions require improved fuels and improved vehicle propulsion systems. Emerging technologies and design tools are leading to attractive light-weight materials and significant reductions in the air resistance and rolling resistance of tires. Internal combustion engines are being continuously improved and their use in a variety of hybrid vehicle designs opens new opportunities. Improvements in standard engine designs can lead to major improvements in vehicle performance during the next decade.

Over the long term, however, the growing complexity of the technologies needed to further reduce air pollutant emissions from ICEVs, the fundamental technological challenges posed by greenhouse warming, and energy security problems will stimulate efforts to explore alternatives to the ICEV. To date, alternative vehicle development efforts have focused on the battery powered electric vehicle (BPEV). This technology can help improve energy security by shifting cars from oil to electricity produced mainly by domestic energy resources. Since they emit zero pollution in their operation, BPEVs can also help improve urban air quality. But if the electricity for these vehicles comes from conventional fossil fuel-powered generators, air quality problems are not eliminated but transformed and transferred from one site to another.

FCEVs are at an earlier stage of development than BPEVs but are likely to be attractive alternatives. They offer the advantages of BPEVs and can be quickly refueled and achieve greater range between refuelings.

Like a battery, a fuel cell converts chemical energy directly into electricity at high efficiency. For motor vehicle applications the electricity produced by the fuel cell drives electric motors that provide power for the wheels. An FCEV would probably use a battery or an "ultra capacitor," patterned after an electrical storage device being developed for the Strategic Defense Initiative, to provide extra power for starts and passing. This electrical storage system can be charged both by the fuel cell operating under low-load conditions or with the energy that would otherwise be lost in braking, via a "regenerative braking" system. The required electrical storage system would be somewhat larger than the battery used in conventional cars but much smaller than the batteries needed for BPEVs.

Fuel cells for cars would likely use hydrogen as fuel, but the fuel delivered to and stored onboard the car could be either hydrogen or a "hydrogen carrier" that is converted into hydrogen onboard the car. If hydrogen is the form of the fuel delivered to the car, it could be stored in various ways -- as compressed gas (the favored option at present), as a liquid, or as a metal hydride -- a compound with a metal that releases the contained hydrogen when heated. Alternatively, methanol could be used as a hydrogen carrier. In this case, hydrogen would be produced onboard by reacting the methanol with steam.

An FCEV fueled by hydrogen would produce only water in operation. An FCEV fueled by methanol would emit water, small amounts of carbon dioxide, evaporative emissions from the methanol storage tank, and pollutants from the operation of the device that converts methanol into hydrogen. The air pollutants, however, would be a tiny fraction of the emissions from an ICEV fueled with gasoline or methanol. System-wide greenhouse gas emissions would also be much less for FCEVs than for alternatives.

Next Steps

The Clinton Administration intends to encourage exploration of all the technological alternatives -- short- and long-term -- that will help us simultaneously improve the environment and the economy. We will support a balanced, long-term research program in renewable energy. We will support development and dissemination of advanced manufacturing technologies. We will work with Congress to create tax, regulatory, procurement, and trade policies that encourage technological innovation and favor efforts that link environmental and economic goals.

We have initiated contacts with the automobile industry that we hope will lead to establishment of a task force -- guided by manufacturers, parts suppliers, and fuel suppliers -- that will coordinate the research efforts of relevant Federal agencies, the national laboratories, and defense facilities in areas related to near-term needs and long-term opportunities for automobiles and fuels. The task force will oversee the establishment of cooperative research ventures in: a) advanced propulsion systems; b) alternative fuels; and c) advanced materials and maufacturing technologies.

We will also coordinate our work with the States. We intend to bring together key State officials and representatives of the participating Federal agencies to: a) design a program to encourage introduction of prototype vehicles; and b) coordinate Federal and State regulatory programs.

The Clinton Administration wants to contribute to the goal of removing the automobile from the list of national environmental problems while working to restore the technological preeminence of the nation's automobile producers. We will establish a partnership with industry and promote policies -- in trade, environmental regulation, federal procurement, etc. -- that, combined with research support, encourage change in the industry but allow industry to prosper as a result of that change.

The work on renewable energy sources and end uses done by many of those individuals who will testify after me today has enabled this change. I appreciate the chance to set the stage for their more detailed descriptions of these exciting technological opportunities and look forward to working with the Committee to shape the government's role in improving the likelihood that these new technologies will take hold and improve our national economic, environmental, and security positions.

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Invited Testimony

at the

Hearing on the Environmental Impacts
of
Accelerated Research and Development in the Renewable Energy Sector

before

The Subcommittee on Research and Development
of the
Committee on Environment and Public Works
United States Senate

March 22, 1993

Mr. Chairman and Members of the Committee, I am pleased to have the opportunity to testify at this important hearing on accelerated research and development on renewable energy. I am a Senior Research Scientist at Princeton University's Center for Energy and Environmental Studies, where I head a research group that carries out energy technology assessments and energy policy analyses.

For the last three years I have been one of the co-ordinators of a study assessing the prospects for producing fuels and electricity from renewable energy sources. The options studied included hydroelectric, wind, solar thermal, photovoltaic, and geothermal power, electricity from biomass, alcohol fuels and hydrogen from biomass, and hydrogen produced electrolytically from wind, photovoltaic, and hydroelectric power sources. This assessment was commissioned by the United Nations Solar Energy Group for Environment and Development, as an input to the United Nations Conference on Environment and Development, which was held in Rio de Janeiro in June 1992. This assessment was carried out by more than 50 of the world's leading renewable energy experts from 11 countries. The study has recently been published by Island Press as the book ***Renewable Energy: Sources for Fuels and Electricity*** [1].

In my testimony, I would like to present some of the general findings of ***Renewable Energy*** and then focus most of my remarks on strategies for moving toward the wide use of hydrogen as a fuel for transportation.

SOME GENERAL FINDINGS RELATING TO RENEWABLE ENERGY

The central finding of ***Renewable Energy*** is that, because of impressive technical progress made during the past decade and the auspicous prospects for further gains, it would be feasible by the middle of the next century, with accelerated research and development and market development efforts, for renewable energy sources to provide more than half the energy needs of an energy-efficient world economy (*see Figure 1*). This could be accomplished competitively at world energy prices that are not much different from present prices, while providing major energy security and environmental benefits--including reduced world dependence on Middle East oil and a reduced risk of global warming from the burning of fossil fuels. Accelerated development of renewable energy is key to achieving sustainable development--bringing a decent living standard to the world's poor and sustaining the economic well being of the industrialized countries in safe, secure, and environmentally acceptable ways.

More specific findings of ***Renewable Energy*** are that:

- By 2050, when the world economy is eight times its present size, renewable energy sources could account for three-fifths of the world's electricity market and two-fifths of the market for fuels used directly.
- Under such a scenario, global carbon dioxide emissions would be reduced to three-quarters of their 1985 level by 2050 (*see Figure 1*).
- A renewables-intensive energy future would be characterized by a diversity of energy sources, the mix of which would vary from region to region.
- Biomass (plant matter), grown in a sustainable manner and converted to

electricity and liquid and gaseous fuels, would account for more than half of all renewable energy (*see Figure 1*).

- Most electricity produced by renewable sources would be fed into large electrical grids and marketed by electric utilities.
- Intermittent renewables (wind, photovoltaic, and solar thermal power) could provide up to one-third of total electricity requirements in most regions without new electrical storage technologies.
- Renewable liquid and gaseous fuels would be sold much like oil and natural gas are today. Large oil companies could become the principal marketers; some could be producers as well.
- Natural gas would play major support roles. Natural gas-fired gas turbines would back up intermittent renewables on electrical grids, and the production of hydrogen and methanol from natural gas would pave the way for later production of these fuels from renewable sources.
- Trade in renewable fuels and natural gas would create competition in world fuel markets, reduce the likelihood of energy price fluctuations and supply disruptions, and eventually stabilize world fuels prices (*see Figure 2*).

USING HYDROGEN FUEL CELLS TO ADDRESS THE CHALLENGES POSED BY TRANSPORTATION

One approach to renewable energy development is to identify, develop, and introduce energy carriers that only modestly affect the existing energy conversion and delivery system. For example, ethanol derived from biomass sources is a liquid fuel that can be transported, stored, and used in internal combustion engines much like gasoline is used today. While the fuel ethanol derived from grain on the market today requires subsidies to compete, advanced enzymatic hydrolysis technologies under development at the NREL would make it possible to produce ethanol from low-cost biomass feedstocks (e.g. wood chips) at costs competitive with gasoline derived from crude oil costing $25 per barrel in the year 2000+ period, if the NREL research and development goals are met [2].

An alternative approach to renewable energy is via options that would be accompanied by fundamental changes in the existing energy system. This approach should be considered if the existing system should be changed. Our personal transportation system is such a system, because of the multiple formidable challenges posed by the gasoline-powered internal combustion engine vehicle.

- The US DOE projects that by 2030 vehicle miles traveled and fuel use by light-duty vehicles will increase by 80% and nearly 3 MMB/D, respectively (*see Table 1*). At the same time domestic oil production is expected to fall from the current level of 9 MMB/D to 4 MMB/D. If the shortfall is compensated by increased oil imports it will mean increased dependence on the Middle East, as it is expected that after 2000 conventional oil production will decline in all regions outside the Middle East.
- Meeting urban air quality goals in the face of expected continuing increases in vehicle miles traveled by light-duty vehicles would require

costly new tailpipe emissions control technologies and a complex system of inspections and violations penalties, if the internal combustion engine vehicle (ICEV) continues to be the technology of choice for personal transportation.

- If the world community were to seek to prevent any further change in the world's climate beyond what we are already committed to by past greenhouse gas emissions, CO_2 emissions would have to be cut 60% or more, according to the Intergovernmental Panel on Climate Change [3]. Some 3/4 of CO_2 emissions from fossil fuel burning worldwide come from fuels used directly (i.e. other than for electric power generation) and more than half of the CO_2 emissions from fuels used directly come from burning oil, mostly in transportation. Transportation is the fastest growing sector that uses fuels directly.

- The US automobile industry, which accounts for more than 1/10 of US manufacturing jobs, has lost technological leadership and market share in both domestic and foreign markets.

A renewable energy strategy that could deal effectively with all these challenges simultaneously probably requires not only the introduction of a a new fuel but also a new vehicular propulsion system--an alternative to the internal combustion engine. The prospects are good that the use of hydrogen fuel cells for personal vehicles and other ground transportation systems would be able to meet all these challenges simultaneously. The rest of my testimony will focus on this element of a renewable energy strategy.

The fuel cell is not just another way to burn fuel. Rather, the fuel cell moves energy conversion beyond the "age of fire" into the "age of electrochemistry"--providing a way to convert the fuel's chemical energy directly into electricity in a device with no moving parts (*see Appendix A and Figure 3*). By removing the intermediate step of combustion to produce heat, the fuel cell offers a quantum leap in energy efficiency and the virtual elimination of air pollution.

Fuel cell electric vehicles (FCEVs) can be powered by hydrogen or a "hydrogen carrier" such as methanol that is converted to hydrogen on-board the vehicle. In the case of methanol, the most likely such carrier for the foreseeable future, this conversion is accomplished by "reforming" the methanol with steam. The main advantage of methanol is that, like gasoline, it is a liquid fuel that is easy to transport and store. But hydrogen can be produced from more primary energy sources than is possible for methanol, and FCEVs operated on hydrogen would be more efficient. FCEVs would be 3-times as energy-efficient as gasoline-fired internal combustion engine vehicles (ICEVs) when fueled with hydrogen and 2 1/2-times as energy-efficient when fueled with methanol.

Alternative Primary Energy Supplies for Fuel Cell Electric Vehicles

Both hydrogen and methanol can be derived from secure energy sources:

- The least costly way to produce both fuels is from natural gas feedstocks.

This can be accomplished with commercially available technology that is widely used in the chemical process industries. The energy efficiency gains from the switch to fuel cell electric vehicles would be far in excess of the processing losses associated with conversion. In the case of hydrogen, the natural gas energy required to meet all the light-duty vehicle demand projected for 2030 would be just 40% of the 9 MMB/D of oil-equivalent energy that would be otherwise be needed (*see Table 1*).

- As natural gas supplies tighten, additional supplies of hydrogen and methanol could be provided by gasification of various biomass feedstocks.[1] Biomass offers the least costly means of producing FCEV fuels from renewable energy sources. The major candidate biomass feedstocks are urban refuse, agro- or forest product-industry waste streams, and biomass crops grown on plantations dedicated to energy production:

  + Because FCEVs would be so energy-efficient, various waste streams could play significant roles. For example, hydrogen derived from urban refuse and urban wood wastes would be adequate to support up to 1/5 of the light-duty vehicle fleet at the level of driving projected for 2030 (*see Table 1*), in the process displacing up to 1.8 MMB/D of oil that would otherwise have to be imported, and creating the jobs needed to support a new "urban energy industry."

  + In the industrialized countries, excess agricultural lands are the leading candidates for establishing plantations. Hydrogen produced from biomass that could be grown on the 75 million acres of croplands (4% of the US land area) now held out of food production either to support farm prices or to control erosion would be adequate to support the entire US light-duty vehicle fleet in 2030, and the energy crops involved could be designed to provide a high degree of erosion control. Growing biomass for energy would provide new sources of income for farmers that would make it possible eventually to phase out most government farm subsidies [5,6].

  + In developing regions, deforested and otherwise degraded lands with sufficient rainfall to support productive vegetation are the leading candidates for energy plantations. Revenues from such plantations could help pay for the land restoration efforts. The amount of lands potentially available for such plantations in sub-Saharan Africa and Latin America are so large that these regions could become major exporters of biomass-derived transport fuels (*see Figure 2*), thereby

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[1] In gasification, a heated mixture of biomass (e.g. woodchips) and steam is transformed into a gaseous mixture consisting mainly of methane, carbon monoxide, hydrogen, and excess steam. This gaseous mixture would subsequently be transformed into either hydrogen or methanol using essentially the same process technologies that would be used to make these fuels from natural gas. Because biomass contains little sulfur and is much more reactive than coal, this route to methanol or hydrogen production is technologically less difficult than producing these fuels from coal. The needed technologies could be demonstrated and commercialized before the turn of the century [4].

bringing competition and price stability to international fuel markets [5,6].

- o Eventually land and water resource constraints will limit further growth in the production of FCEV fuels from biomass, but additional supplies of hydrogen could be provided by electrolysis using wind and direct solar electric power sources:

  - + Electricity produced from new wind farms is already less costly than electricity from new fossil fuel power plants, in areas having good wind resources [7]. While most existing wind farms are in California, the largest wind resources are in the 12 states of the Great Plains, which account for over 90% of the US wind energy potential (*see Table 2*). While initially the wind resource in this region will be exploited to serve local electrical markets, only a tiny fraction of the potential can be exploited this way, because the wind electricity generation potential is 25 times as large as total present electricity generation in the region. A much greater fraction of the resource can be exploited if the resource is also used to to produce hydrogen for transportation [10]. Some 15% of the wind energy potential of the Great Plains, requiring wind turbines on 3.5% of the land area of these states (1.6% of total US land area) would be adequate to provide the fuel needed to support all US light-duty vehicles in 2030 (*see Table 2*).

  - + While the costs of photovoltaic (PV) electricity have fallen substantially over the last decade, the present cost is still much higher than PV's value for large-scale utility applications. However, with an accelerated research and development effort and aggressive pursuit of near-term niche markets where high cost PV is already competitive, PV could become highly competitive for grid-connected utility applications during the first decade of the next century [8,9]. As in the case of wind power, PV resources could begin to be exploited for electrolytic hydrogen production after first exploiting the resource to serve local electricity markets. Only 0.2% of the US land area would be required for the solar collectors needed to provide all the hydrogen to run the US light-duty vehicle fleet in 2030. Because so little water is required for electrolysis, PV hydrogen could even be produced in arid regions [10].

Environmental Aspects of Fuel Cell Electric Vehicles

FCEVs would also have superb environmental characteristics, even taking into account the pollution associated with producing the fuels. Hydrogen-powered FCEVs emit only water vapor, and methanol-powered FCEVs only carbon dioxide and tiny amounts of local air pollutants, along with water vapor. On a system-wide basis greenhouse gas emissions for FCEVs operated on methanol or hydrogen derived from natural gas would be less than half of those for gasoline ICEVs, while they would be reduced 90 percent or more for FCEVs operated on fuels derived from renewable sources (*see Figure 4*).

Performance and Cost Characteristics of Fuel Cell Vehicles

If FCEVs are to be an instrument for restoring the competitiveness of the US automobile industry, they not only have to be clean and be operated on secure energy sources, but also they have to be perceived by consumers as attractive alternatives to ICEVs.

Preliminary analyses indicate that fuel cell-electric vehicles can be built with performance, range, and refueling characteristics that are comparable or superior to those for ICEVs. They would generally be more responsive and much quieter and would require less maintenance.

Fuel cell-powered vehicles are at an earlier stage of development than battery-powered electric vehicles (BPEVs) but are likely to be attractive alternatives: they offer the advantages of BPEVs but they can be refueled quickly and the achievable range between refuelings would probably be longer than for BPEVs [5,11].

The only commercially available fuel cell, the phosphoric acid fuel cell, is not suitable for use in light-duty vehicles (*see Appendix B*). However, over the last several years the proton-exchange-membrane fuel cell (*see Appendix C and Figure 3*) has emerged as a strong candidate for these applications. This fuel cell and ancillary equipment would be compact enough to use in cars, and recent developments indicate that there are now no fundamental barriers to producing FCEVs with this technology at competitive costs.

Although costs of prototype fuel cells are high and costs for routinely produced FCEVs cannot be determined with precision until engineering designs are more fully developed, some general considerations provide a basis for thinking that a fuel cell car would not cost much more than an internal combustion engine car. Moreover, because the fuel cell car would have a much lower operating cost, the lifecycle cost of owning and operating the fuel cell car, in cents per mile, would be less than the lifecycle cost of a gasoline-powered car with an internal combustion engine.

<u>The Initial Cost</u>: If the FCEV were to succeed in completely displacing the ICEV, it would have to be produced at a rate of about 10 million vehicles per year, just to meet the US market demand. Thus, after a learning period, the economies of mass production would determine its selling price. As a general rule, the cost for a new technology in mass produced volumes can be estimated from considerations of the costs of the raw materials involved and the costs of fabrication for similar well-established technologies, unless the new technology involves exotic materials or fabrication techniques.

The platinum catalyst (*see caption for Figure 2*) is the only scarce material required for the manufacture of the proton exchange membrane fuel cell. Until recently, the platinum catalyst requirements were so high that it was generally believed that the high platinum cost would make it virtually impossible for the proton exchange membrane fuel cell to compete in automotive markets. But recent research advances have reduced the platinum requirements by a factor of 40, to about 0.1 troy ounce per car (about twice the platinum requirements for the catalytic converter used in the exhaust gas cleanup system of an ICEV today) [11]; if this laboratory performance can be achieved routinely in road vehicles, the "platinum problem" will be solved.

The only other costly component of a fuel cell is the membrane electrolyte (*see caption for Figure 3*). Current membranes cost several thousand dollars per car. However, the membrane currently favored is available only in small quantitiea, since it is not a commercial product. The manufacture of this membrane does not require procedures that are extraordinarily different from what is required for a wide variety of other polymer membranes. Accordingly, if the membrane were marketed and demand for it were to increase, two things would happen: the economies of mass production would come into play and research and development on alternative membranes would intensify. As a result, costs would fall sharply. Indeed, experience with polymer membranes (e.g. Teflon) and many other petrochemical products shows that such products tend to follow classical learning curves, with costs declining typically 20 percent for each cumulative doubling of production. Taking into account such considerations, FCEV cost and performance modelling studies indicate that in the period shortly beyond the turn of the century membrane costs per car could be reduced to the range $300 to $400 per car [11,12].

Materials other than the catalyts and the membrane required for the proton exchange membrane fuel cell are relatively commonplace, so that their costs in mass production can be estimated in a relatively straightforward manner.

In one FCEV study it is estimated that the cost for the fuel cell system, the electrical storage device that would be used to meet peak loads, the electric motor system required to drive the wheels, various pieces of auxiliary electrical equipment, and cannisters for compressed hydrogen storage would cost about $4000, compared to a cost of $3000-$4000 for the ICEV equipment that would be displaced, so that the incremental cost for the FCEV would be $0 to $1000 per car [12]. Another analysis indicates that a fuel cell electric car would cost $6700 more than a car with an internal combustion engine [13].

The Lifecycle Cost: Even if their first costs prove to be significantly higher than for ICEVs, FCEVs could still be competitive with ICEVs because of their very low operating costs. Fuel cell cars would have far fewer moving parts and no explosive combustion processes. As a result, fuel cell cars can be expected to have lower maintenance costs. Moreover, because the fuel cell and ancillary equipment would last longer than the replaced ICEV equipment [11], it is entirely possible that these components could be removed from retired vehicles and recycled. Also, because fuel cell cars would be 2 1/2 to 3 times as energy-efficient as today's new cars, they would use much less fuel. This feature makes it possible for fuels derived from renewable sources to be competitive, even if the fuel price (in dollars per gallon of gasoline-equivalent) paid by the consumer is much higher than the price of gasoline.

Comparisons of lifecycle costs for alternatives to the gasoline ICEV are shown in Figure 5 for medium-term options (a BPEV and FCEVs fueled with hydrogen and methanol derived from natural gas and biomass) and in Figure 6 for long-term options [a BPEV and FCEVs fueled with hydrogen derived electrolytically from wind electricity, PV electricity produced in areas of high insolation (e.g. the US Southwest) and PV electricity produced in areas of moderate insolation (e.g.

the US average insolation)]. These lifecycle costs were calculated for vehicles with the characteristics summarized in Table 3, based on a model for evaluating the performance and costs of alternative vehicles developed by Mark DeLuchi at the University of California at Davis [11].

For the medium term (the first decade of the 21st century), both the natural gas and the biomass-based FCEV options are estimated to be less costly per km than either the BPEV or the ICEV run on gasoline derived from crude oil costing $25/barrel, even though the delivered costs of the biomass-derived fuels are 1/3 to 2/3 higher than the price of gasoline (see Figure 5), and the assumption that the FCEV would cost about $8,900 more than the ICEV (*see Table 3*). This possibility arises in large part from the savings associated with the much higher fuel economy and the expected reduced maintenance costs for FCEVs.

For the long term (beyond the first decade of the 21st century), the costs per km for the FCEV options are comparable to the cost per km for the BPEV but higher than the cost per km for the ICEV--but only modestly higher, despite the fact that the delivered prices of hydrogen from wind and PV electricity are three to four times the delivered price of gasoline ($3.9 to $5.6 per gallon of gasoline equivalent for PV hydrogen vs. $1.25 per gallon for gasoline).[2]

This analysis underscores the importance of using lifecycle costs, not fuel prices, in assessments of alternative transportation options. If fuel price were the yardstick used in making fuel/vehicle choices, the renewable options would not be selected (unless gasoline were heavily taxed), because the renewable fuels would tend to be much more costly.

ELEMENTS OF A FUEL CELL VEHICLE DEVELOPMENT STRATEGY

Though a shift to fuel cell vehicles would be a radical innovation, the technology for both the vehicles and the fuels could be brought to commercial readiness in a decade's time, with committed public and private efforts. The Administration's new "clean car initiative" is a good start.

Technologically, what is needed includes accelerated research and development on:

- Various fuel cell technologies potentially suitable for motor vehicle applications
- Ancillary fuel cell vehicle components, including hydrogen and electrical storage options and control technologies

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[2] The cost per km indicated in Figure 6 for the PV hydrogen options is 5% higher than for the ICEV in areas of high insolation and 9% higher in areas of moderate insolation--estimated assuming that a hydrogen FCEV would cost about $8900 more than an ICEV (*see Table 3*). Using instead DeLuchi's latest estimate of $6700 for the incremental cost of the FCEV [13], the cost per km for the PV hydrogen-powered FCEV would be the same as for the ICEV in areas of high insolation and 5% higher than for the ICEV in areas of moderate insolation.

- o Design of integrated fuel cell vehicles
- o Construction and field-testing of a variety of FCEVs under real-world driving conditions
- o The technologies for producing FCEV fuels from biomass (including urban and other waste resources)
- o Techniques for establishing biomass plantations on degraded lands (especially in developing countries)
- o Techniques for achieving high, sustainable yields of biomass on plantations in ecologically sensible ways under a wide range of growing conditions
- o Electrolysis systems optimized for use with intermittent renewable electricity sources
- o Wind, photovoltaic, and solar thermal energy systems (focused at this point mainly on electricity, not hydrogen production)
- o Infrastructure for producing and marketing fuels for FCEVs
- o The formulation of development paths that would lead quickly and efficiently to the goal of a new generation of clean motor vehicles that would be competitive in domestic and world markets.

The needed research and development must be closely coordinated with market development efforts. Experience in a wide range of industries shows that cost reductions are highly correlated with cumulative production, rather than simply with time, with costs typically declining 20% for each cumulative doubling of production in fast-growing industries where innovation is nurtured [14].

In the case of fuel cells, substantial efforts should be made to identify and exploit "high value" markets (e.g. residential cogeneration) that will be cost-effective before fuel cell costs are low enough for fuel cells to compete in motor vehicle markets. In motor vehicle markets, initial efforts should probably be focussed on high value markets such as buses, before developing the automotive market.

In the case of natural gas, the introduction of compressed natural gas for use in ICEVs now could provide an experience base that would facilitate a later shift to the use of compressed hydrogen for use in FCEVs.

In the case of biomass, it is very likely that electricity markets will be developed before the fuels markets for FCEVs [15]. Efforts aimed at speeding up the development of these electricity markets--e.g. research and development on the growing of biomass for energy, measures to encourage farmers to grow energy crops, and the demonstration of advanced biomass-electric generating technologies, would create a biomass energy industry that would be ready to serve transportation markets by the time natural gas supplies are no longer adequate to fully satisfy the demands of a growing FCEV fleet.

Likewise in the case of wind, photovoltaic, and solar thermal electric energy, exploiting power generation markets first would bring down costs and thereby facilitate a subsequent expansion of the market to FCEV applications.

In the case of electrolysis, developing initial niche markets based on low-cost off-peak hydroelectric power would bring down electrolysis costs, thereby facilitating a shift later to wind, photovoltaic, and solar thermal resources, by the time the FCEV market needs these much larger electrolytic hydrogen sources.

Policymakers should give high priority to identifying the most capable groups drawn from the private sector, the national laboratories, and our universities, for each of the tasks involved in implementing a FCEV atrategy, and to fostering the interactions needed among these groups, to move ahead quickly and efficiently.

Despite the importance of renewable energy, hydrogen and hydrogen carriers, and fuel cells for transportation, in meeting sustainable development goals, research and development priorities both in this country and in other industrialized countries have given these options relatively low priority in the overall energy research and development effort. For OECD countries, overall expenditures for conservation (which includes fuel cells and many other technologies as well) and renewable energy accounted in 1991 for just 14% of all energy R&D expenditures, compared, for example, to 54% for the overall nuclear energy R&D effort (*see Table 4*). There seems to be an imbalance here that should be redressed. A high priority in energy policymaking should be to articulate clearly what our economic, environmental, and security goals are relating to energy, and assign new energy R&D priorities accordingly.

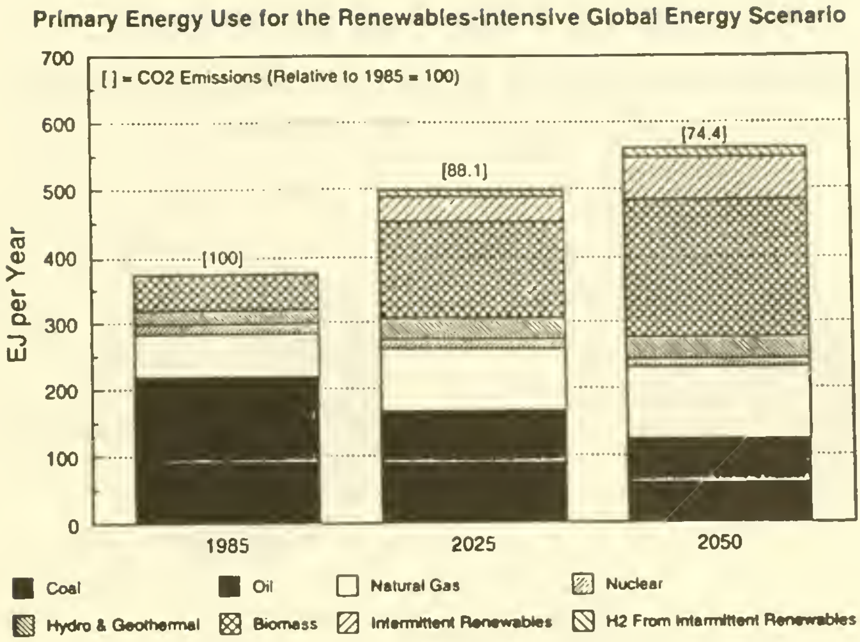


Figure 1.

Global primary energy requirmenta for a renewables-intenaive global energy acenario

This figure shows global primary energy requirementa for the renewablea-intenaive global energy scenario developed in [5] in an exerciae carried out to indicate the future prospects for renewable energy for each of 11 world regions. In developing this scenario, the high economic growth/high energy efficiency demand projections for solid, liquid, and gaseous fuels and electricity developed by the Response Strategies Working Group of the Intergovernmental Panel on Climate Change [3] were adopted in [5] for each world region. For each region a mix of renewable and conventional energy aupplies was constructed in [5] to match these demand levels, taking into account relative pricea, regional endowments of conventional and renewable energy sources, and environmental constraints.

The primary energy associated with electricity produced from nuclear, hydroelectric, geothermal, photovoltaic, wind, and aolar thermal-electric aources is assumed to be the equivalent amount of fuel required to produce that electricity, assuming the average heat rate (in MJ per kWh) for all fuel-fired power-generating units in a given year. This global average heat rate is 8.05 MJ per kWh in 2025 and 6.65 MJ per kWh in 2050.

For biomass-derived liquid and gaseous fuels the primary energy is the energy content of the biomass feedstocks delivered to the biomass energy conversion facilities.

Primary energy consumption in 1985 includes 50 EJ of non-commercial biomass energy [6]. It is assumed that there is no non-commercial energy use in 2025 and 2050.

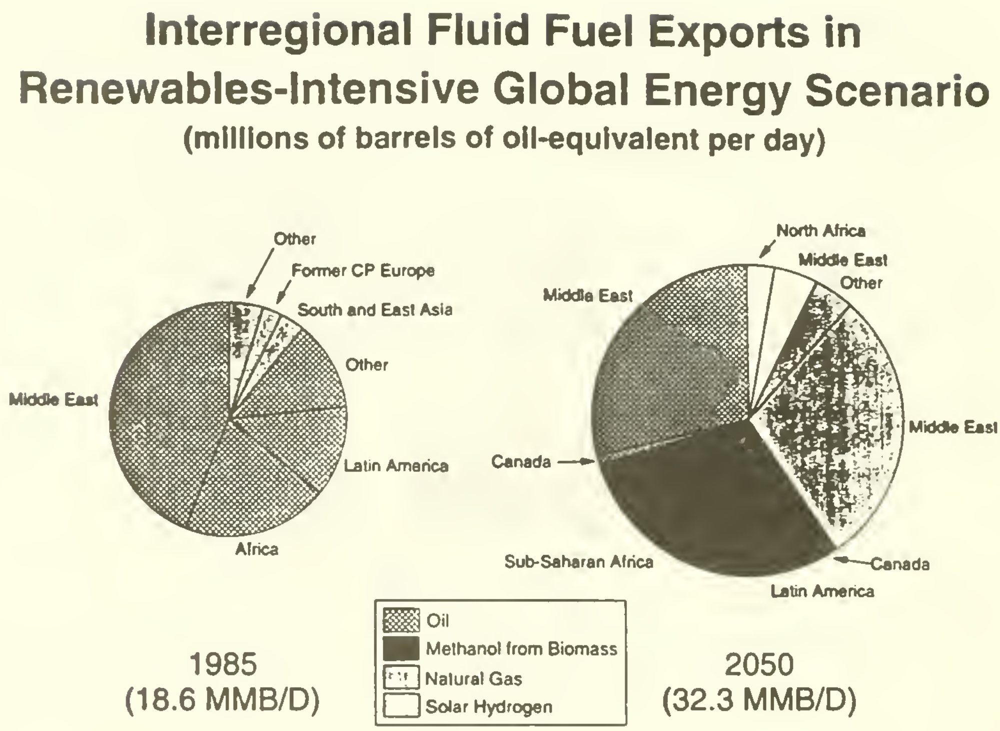


Figure 2.

Interregional fuels flows for a renewables-intensive global energy scenario

The importance of world energy commerce for the renewables-intensive global energy acenario developed in [5] and for which global primary energy consumption is shown in Figure 1 is illustrated here. The figure shows that by the middle of the next century there would be comparable interregional flows of oil, natural gas, and biomass-derived methanol, as well as small flows of hydrogen derived from renewable sources. This diversified supply mix is in sharp contrast to the situation today, where oil dominates international commerce in liquid and gaseous fuels.

Most methanol exports would originate in sub-Saharan Africa and in Latin America, where there are vast degraded land areas suitable for revegetation that will not be needed for cropland [6]. Growing biomass on such lands as feedstocks for producing methanol (or other biomass fuels) would provide a powerful economic driver for restoring these lands.

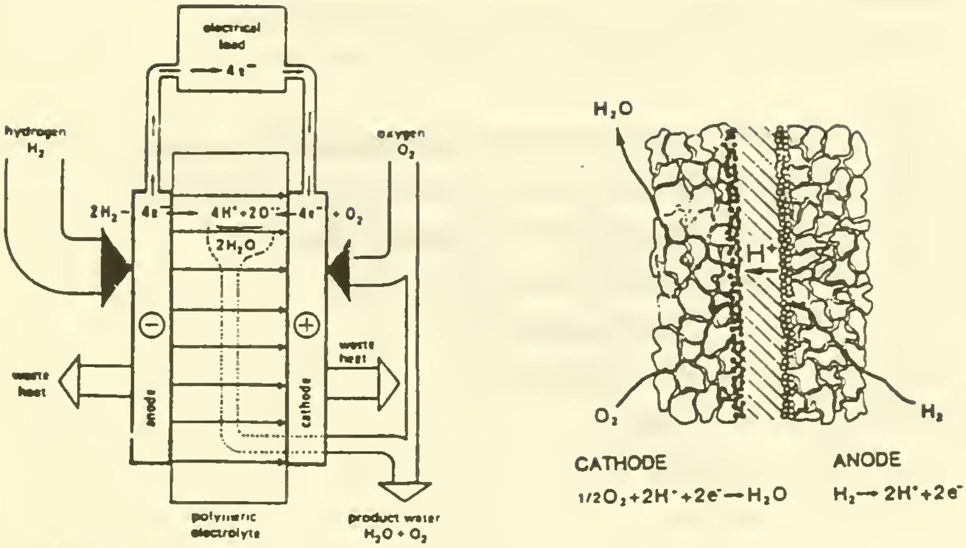


Figure 3.

The operating principle of a hydrogen fuel cell.

A hydrogen fuel cell converts the chemical energy in hydrogen directly into electricity. Its key features are the anode and cathode, at which the energy conversion process takes place, and the electrolyte (*see figure on the left*). Hydrogen fuel gives up electrons to the porous anode, creating a current in the wire leaving the anode. The intrinsic tendency for the hydrogen to react with oxygen is manifested as a voltage that drives the electrons through the electrical load to the cathode, where they combine with oxygen molecules from the air to form oxygen ions. The build-up of positive ions at the anode and negative ions at the cathode would soon stop the process unless there were a way to dissipate these charges. This is accomplished by the electrolyte, an insulating material that is permeable to the flow of hydrogen ions but not to hydrogen and oxygen gases. The hydrogen ions migrate through the electrolyte to the cathode, where they combine with oxygen ions to form water.

A strong candidate fuel cell option for use in light-duty vehicles is the proton-exchange membrane fuel cell, so-called because it uses a thin (about 100 microns thick--approximately the thickness of a human hair) solid polymer membrane for the electrolyte. Currently the membrane of choice is a fluorocarbon polymer similar to Teflon, to which are attached sulfonic acid groups, forming perfluorosulfonic acid.

The electrodes, separated by the the membrane, are thin sheets of a porous conducting material to which small amounts of platinum are applied on the membrane side (*see figure on the right*). The platinum is needed to catalyze the reactions at the electrodes, because otherwise the reactions would proceed too slowly at the fuel cell's low operating temperature (less than 200 °F)

A single membrane/electrode assembly, the heart of the fuel cell, is less than four-hundredths of an inch thick. A fuel cell "stack" is constructed by connecting in series many such assemblies, stacked one on top of another.

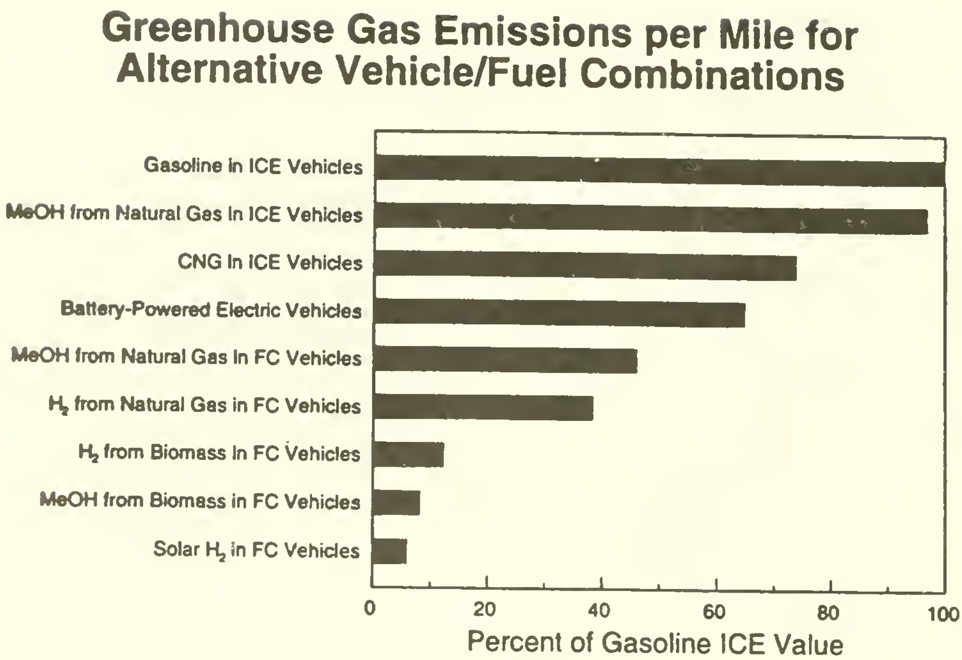
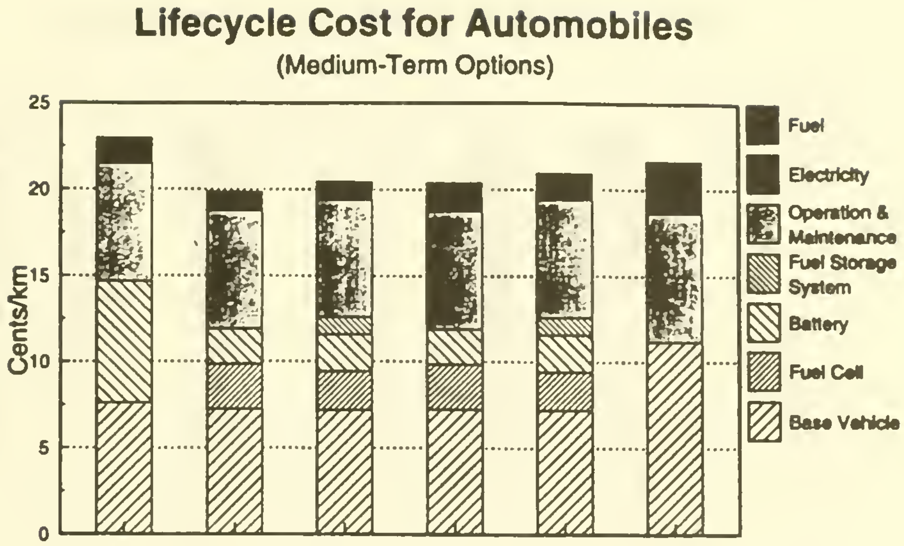


Figure 4.

Greenhouse gas emissions per km from alternative vehicles relative to emissions from internal combustion engine vehicles powered with reformulated gasoline in the year 2000.

The greenhouse gas (GHG) emissions include both carbon dioxide and other greenhouse gases emitted throughout the entire fuel cycle, as well as the direct emissions from the vehicle. The biomass methanol (MeOH) and hydrogen (H_2) options include the GHG emissions from the fossil fuels used to grow, harvest, and transport the biomass to the conversion facility. The compressed natural gas (CNG) and hydrogen options include the GHG emissions from the power plants that provide the electricity to compress these gases to high pressure at the refueling station, assuming the electricity needed to run the compressors is provided by the average mix of US electric power sources in the year 2000.

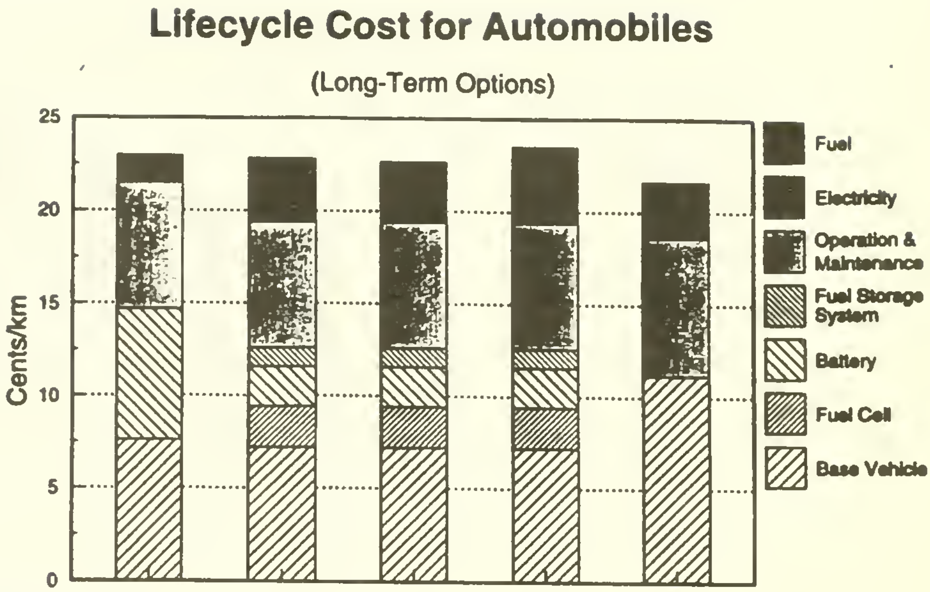


VEHICLE TYPE	BPEV	FCEV	FCEV	FCEV	FCEV	ICEV
ENERGY SUPPLY	Ave. US Elect.	NG → MeOH	NG → H_2	Biomass → MeOH	Biomass → H_2	Petroleum → Gasoline
PRODUCTION COST ($/GJ)	–	4.8	4.0	8.8	8.3	–
DELIVERED COST ($/GJ)	22.0 (7.9 cents/kWh)	8.6	9.7	12.6	14.0	9.5

Figure 5.

The lifecycle cost (in cents/km) of alternative automobiles--medium-term options.

These automobiles have the characteristics indicated in Table 3: a battery-powered electric vehicle (BPEV) run with residential electricity costing 7.9 cents/kWh (US residential price projected for the year 2000); fuel cell electric vehicles (FCEVs) operated on methanol (MeOH) and hydrogen (H_2) derived from natural gas (NG) and biomass; an internal combustion engine vehicle (ICEV) operated on gasoline derived from crude oil costing $25/barrel. The retail fuel tax is included in O&M expenses and is assumed to be the same (0.74 cents/km--corresponding to $0.31/gallon of gasoline) in all cases. It is assumed that MeOH is produced from low-cost feedstocks available overseas (NG costing $1.5/GJ and biomass costing $2.0/GJ) and includes an overseas transport cost of $1.0/GJ of produced MeOH. It is assumed the H_2 is produced from domestic sources (NG costing $2.0/GJ and biomass costing $3.0/GJ). The automotive cost model is developed in [11]. The cost model for producing MeOH and H_2 fuels from NG and biomass feedstocks is developed in [4] and [16]. Fuel costs are evaluated assuming a 10% real discount rate and a 0.5% per year insurance cost, neglecting corporate income and property taxes.



VEHICLE TYPE	BPEV	FCEV	FCEV	FCEV	ICEV
ENERGY SOURCE	Ave. US Source Mix	wind	pv/high insolation	pv/moderate insolation	petroleum
ENERGY CARRIER	electricity	→ H_2	→ H_2	→ H_2	→ gasoline
PRODUCTION COST ($/GJ)	–	23.6	21.8	29.1	–
DELIVERED COST ($/GJ)	22.0 (7.9 cents/kWh)	31.3	29.8	37.4	9.5

Figure 6.

The lifecycle cost (in cents/km) of alternative automobiles--long-term options.

These automobiles have the characteristics indicated in Table 3: a battery-powered electric vehicle (BPEV) run with residential electricity costing 7.9 cents/kWh (US residential price projected for the year 2000); fuel cell electric vehicles (FCEVs) operated on hydrogen (H_2) produced electrolytically from wind power costing $0.05/kWh (see note b, Table 2) and from dc photovoltaic (PV) power at costs projected for the period around 2010 [8]--$0.05/kWh in areas of high insolation (2400 kWh per m^2/year--characteristic of the US Southwest) and $0.067/kWh in areas of moderate insolation (1800 kWh per m^2 /year--the US average insolation); and an internal combustion engine vehicle (ICEV) operated on gasoline derived from crude oil costing $25/barrel. The retail fuel tax is included in O&M expenses and is assumed to be the same (0.74 cents/km--corresponding to $0.31/gallon of gasoline) in all cases. The automotive cost model is developed in [11]. The costs for wind and PV power and electrolysis are estimated assuming a 10% real discount rate and a 0.5% per year insurance cost, neglecting corporate income and property taxes.

Table 1. Parameters relating to US passenger vehicles, as projected by the US DOE for the National Energy Strategy[a]

	1990	2000	2010	2020	2030
Population (10^6)	251	269	283	294	301
Vehicle miles traveled (10^{12}/yr)	1.764	2.148	2.667	3.060	3.185
Ave. on-the-road fuel economy (mpg)	18.8	20.6	21.3	22.7	23.2
Gasoline requirements					
(10^9 gal/yr)	93.8	104.3	125.2	134.8	137.3
(MMB/D)	6.12	6.80	8.17	8.79	8.96
(Quads/yr)	11.7	13.0	15.7	16.9	17.2

[a] Source: [17].

Table 2. Wind Electricity Potential in 12 Great Plains States and US Total[a-e]

	State Land Area (10^3 km)	Class ≥5: % of Land Area	Class ≥5: TWh per yr	Class 4: % of Land Area	Class 4: TWh per yr	Class 3: % of Land Area	Class 3: TWh per yr	Total: % of Land Area	Total: TWh per yr	Elect. Prod., 1990 (TWh/yr)
MT	376.56	2.2	180	8.9	550	14.8	710	25.9	1440	25.7
ND	183.11	8.7	320	46.0	1370	0.3	-	55.0	1690	26.8
SD	196.72	0.4	20	34.2	1090	13.0	320	47.6	1430	6.4
MN	206.03	0.0	-	19.5	650	10.1	260	29.6	910	41.6
WY	251.20	4.8	300	10.1	410	10.4	410	25.3	1120	39.4
NE	198.51	0.0	-	10.6	340	34.8	870	45.4	1210	21.6
IA	144.95	0.0	-	10.4	250	28.8	530	39.2	780	29.0
CO	268.31	0.1	-	9.3	410	7.6	260	17.0	670	31.3
KS	211.81	0.0	-	15.7	540	35.6	950	51.3	1490	33.9
OK	177.82	0.0	-	14.4	420	26.6	600	41.0	1020	45.1
NM	314.26	0.2	10	1.3	70	13.4	530	14.9	610	28.5
TX	678.62	0.0	-	4.2	460	14.0	1200	18.2	1660	234.0
12	3207.90	1.2	830	12.6	6560	16.2	6640	30.0	14030	563.3
US	7675.27	0.6	1000	5.4	6740	7.5	7280	13.5	15020	2808.2

a The land areas in each wind class with moderate land-use restrictions (excluding 100% of environmentally sensitive and urban lands, 50% of forested lands, 30% of agricultural lands, 10% of range lands) [18].

b The power density at 50 m hub height, wind electricity generation potential per unit land area, and future cost of electricity by power class are:

	Power Density (Watts/m^2)	Electricity Generation Potential[c] (GWh/km^2/yr)	Electricity Price[d] (c/kWh)
Class 3	350	12.65	6.4
Class 4	450	16.27	5.0
Class 5	550	19.88	4.1

c For turbine arrays with a spacing of 5D x 10D (8 turbines per km^2 for D = 50 m), a 35% conversion efficiency, and 25% array losses.

d This is the estimated cost of wind power for a 1,000 kW_e advanced wind turbine in a Class 4 wind regime [7], for which the installed capital cost is $750 per kW_e, the capacity factor is 35%, and array losses are 25%. Also, a 10% real discount rate, and a 25-year plant life are assumed, and corporate income and property taxes are neglected. The costs for other wind regimes are assumed to vary inversely with wind power density.

e Assuming 85% efficient electrolyzers and 96% efficient rectifiers, the corresponding electrolytic hydrogen production potential (in EJ/yr) is:

	Class ≥5	Class 4	Class 3	Total
12 Great Plains States	2.44	19.27	19.51	41.22
US total	2.94	19.80	21.39	44.13

Table 3. Characteristics of alternative vehicles[a]

	BPEV[b]	MeOH/FCEV[c]	H_2/FCEV[c]	ICEV
EPA test weight[d] (kg)	1462	1275	1256[e]	1371
km driven annually	22,960	22,960	22,960	17,837
Range between refuelings (km)	400	440[f]	400	640
Vehicle lifetime (years)	11.2	11.2	11.2	10.8
Selling price[g] ($)	28,247	24,810	26,143[h]	17,302
Fuel economy				
[1/100 km gasoline-equivalent]	1.96	3.79	3.17	9.08
[mpg gasoline-equivalent]	120	62.1	74.2	25.9
Maintenance cost ($/year)	388	450	434	516

[a] From [11], except where otherwise noted.

[b] The battery used in this design is an advanced bipolar Li/S battery.

[c] In DeLuchi's fuel cell electric vehicle design (see note a) the peaking battery is recharged by an external electricity source (i.e. at home at night). Here an alternative design is considered for which the battery is instead recharged by consuming extra fuel carried onboard the vehicle.

[d] The EPA test weight is the weight of the vehicle with one passenger and a fuel tank that is 40% full.

[e] This is 18 kg more than the weight of the vehicle designed by DeLuchi [11], to allow for the 25.9% increased storage capacity needed when recharging is accomplished by consuming extra fuel carried onboard, while keeping the range between refuelings constant at 400 km.

[f] This is 120 km less than the range of the vehicle designed by DeLuchi [11], to allow for the 27.7% increased storage capacity needed when recharging is via consuming extra fuel carried onboard, for a tank of the same size.

[g] The retail price breakdown for the BPEV and the hydrogen-powered FCEV is:

	BPEV	FCEV
Traction battery and auxiliaries	$13,625	$4,205
Hydrogen fuel storage	0	3,389[g]
Fuel cell stack and auxiliaries	0	4,496
Extra support structure for EV because of added weight	34	(14)
Extra weight and drag-reduction measures for EV	107	107
Difference between EV and ICEV powertrain	(2,839)	(3,298)
Net increment above ICEV cost	$10,921	$8,885

[h] This is $697 more than for the vehicle designed by DeLuchi [11], to allow for the 25.9% increased storage capacity needed when recharging is accomplished by consuming extra fuel carried onboard, while keeping the range between refuelings constant at 400 km. More recently DeLuchi has estimated that the incremental retail price of a hydrogen-powered FCEV would be $6,640 more than for an ICEV under these conditions, instead of $8,890 [13].

Table 4. Government Energy R&D Expenditures in 1991[a] (US $$10^9$)

	France	Germany	UK	Japan	US	OECD
Coal	5.3	67.8	5.6	194.6	658.8	989.3
Oil and Gas	37.2	7.0	7.0	90.8	109.4	374.8
Conservation	50.3	21.5	31.2	16.0	217.5	583.2
Renewables						
Solar Heating	2.1	17.8	4.1	3.6	2.6	52.9
Photovoltaics	4.3	59.2	-	52.1	47.1	198.2
Solar Thermal Electric	-	4.1	-	-	20.0	37.6
Wind	0.5	15.1	14.4	4.0	11.5	95.9
Ocean	-	-	4.8	0.8	2.7	11.0
Biomass	4.8	3.5	5.0	4.0	37.0	106.6
Geothermal	3.4	4.9	3.5	38.9	29.3	90.5
Subtotal	15.1	104.7	31.8	103.4	150.1	592.7
Nuclear Fission						
Breeder	45.2	40.1	106.3	480.5	-	675.2
Other	362.9	131.3	36.6	1573.7	538.5	2914.4
Subtotal	408.1	171.4	142.9	2054.2	538.5	3589.6
Nuclear Fusion	48.0	124.4	35.5	221.7	283.9	896.1
Misc.[b]	-	8.1	13.3	167.0	578.4	1267.7
Total	564.3	504.9	267.2	2847.8	2536.7	8293.5

[a] Source: [19].

[b] Includes electricity transmission, electrical storage, energy systems analysis, and other.

Appendix A: FUEL CELLS FOR MOTOR VEHICLES

Like a battery, a fuel cell converts chemical energy directly into electricity at high efficiency (*see Figure 3*). But unlike a battery, which must be recharged after discharge, the chemical energy powering the fuel cell is contained in fuel stored in a separate container.

For motor vehicle applications the electricity produced by the fuel cell drives electric motors, which in turn, provide power for the wheels. A fuel cell electric vehicle (FCEV) would probably use a battery or an "ultra-capacitor," patterned after an electrical storage device being developed for the Strategic Defense Initiative, to provide extra power for starts and passing. This electrical storage system can be charged both by the fuel cell operating under low-load conditions or with the energy that would otherwise be lost in braking, via a "regenerative braking" system. The required electrical storage system would be somewhat larger than the battery used in conventional cars but much smaller than the batteries needed for battery-powered electric vehicles (BPEVs).

While all practical fuel cells for cars would use hydrogen as fuel, the fuel delivered to and stored onboard the car could be either hydrogen or a "hydrogen carrier" that is converted into hydrogen onboard the car.

If hydrogen is the form of the fuel delivered to the car, it could be stored in various ways--as a compressed gas (the option favored at present), as a liquid, or as a metal hydride--a compound with a metal that releases the contained hydrogen when heated. Hydrogen's main advantages are that vehicle emissions would be zero and that a much wider range of primary energy soucrces could be exploited than is possible with methanol. Also, with hydrogen, the complications of methanol conversion on-board the car are avoided.

Although storing gaseous hydrogen requires bulky containers, the shift from an ICEV to a FCEV makes the storage problem manageable. While hydrogen has an energy density just one-third of that for natural gas, a hydrogen FCEV would be three times as energy-efficient as a compressed natural gas-fired ICEV, so that storage volumes would be the same for the same storage pressure and same range between refuelings. Cannisters storing enough hydrogen at 8000 pounds per square inch for a 250-mile range between refuelings would occupy a volume of less than 30 gallons [11].

Hydrogen is perceived by many people as a dangerous fuel. While the hazards of hydrogen are different from those of the various hydrocarbon fuels now in use, they are not greater [5,11, 12]; as for any fuel, appropriate safety procedures must be followed.

If methanol is used as a hydrogen carrier, hydrogen would be produced onboard by reacting the methanol with steam. As a liquid fuel, methanol is easy to transport and store. Other hydrogen carriers are also possible. One novel approach involves use of powered iron; steam from the fuel cell is reacted with the iron to form rust and hydrogen fuel; after a tankful of iron is completely "rusted out," it is exchanged at the refueling station for a tank of fresh iron, and the rust is reprocessed back to iron [10].

Appendix B: THE PHOSPHORIC ACID FUEL CELL

Management consultants at Arthur D. Little International project that worldwide markets for fuel cells will reach 4,000 MW_e (equivalent to four large nuclear power plants) per year by 2000 [20]. Nearly all of this capacity is expected to be based on the phosphoric acid fuel cell, the only commercially available fuel cell. Being marketed aggressively by the Japanese, this technology will be used in this time period primarily for small-scale, dispersed combined heat and power (cogeneration) applications using natural gas as fuel.

Plans are also underway to introduce this fuel cell for transportation applications such as buses, where the economics seem promising. Although the initial capital costs for phosphoric acid fuel cell buses are expected to be somewhat higher than for the diesel buses they would displace, lower fuel and operating costs would offset the capital cost penalty [21], even without taking into account the energy security and air quality benefits.

In the US, the Department of Energy has a program to demonstrate the use of phosphoric acid fuel cells in urban buses using methanol as fuel. Under this program three prototype 25-passenger buses are being built by the H-Power Corporation of New Jersey, to be delivered to the Department of Energy by the fall of 1994 for controlled testing. This will be followed by field testing of small bus fleets, beginning in 1995.

While well-suited for buses, the phosphoric acid fuel cell is inappropriate for automobiles, because it is too bulky and because costs are not likely to fall to levels where this propulsion system could compete with the automotive internal combustion engine.

Appendix C: THE PROTON EXCHANGE MEMBRANE FUEL CELL

The proton exchange membrance fuel cell was developed initially for space applications, with early work carried out mainly by the General Electric Company for the NASA space program. It was chosen for the Gemini space mission in 1962, because it was found to be the lightest, most compact power source for this application. By the mid-1960s a membrane had been found that increased the operating life to over 57,000 hours (ten times the operating life required for cars!) and offered the potential for very low maintenance [22]. Despite these promising developments, the proton exchange membrane fuel cell lost to the alkaline fuel cell in the competition for the Apollo program and was largely neglected thereafter for space applications. The technology was resurrected in 1983, when the Canadian Department of National Defense began supporting development work at Ballard Power Systems, Inc., after concluding that this technology could serve some military power needs (e.g. for submarines) and have commercial applications as well [22]. Since then, there has been considerable development of the technology--at Ballard in Canada, at the Los Alamos National Laboratory, Texas A&M University, and H-Power, Hamilton Standard, and the International Fuel Cells Corporations in the US, and at Siemens in Germany. The technology has evolved to the point where it is now being seriously considered for various commercial applications, including use in light-duty vehicles.

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RESEARCH, DEVELOPMENT, AND DEMONSTRATION EFFORTS IN THE LOS ANGELES AREA TO PROMOTE HYDROGEN AS AN ALTERNATIVE FUEL

Presented Before the United States Senate
Committee on Environment and Public Works
Subcommittee on Toxic Substances and Research and Development
March 22, 1993

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RESEARCH, DEVELOPMENT AND DEMONSTRATION EFFORTS IN THE LOS ANGELES AREA TO PROMOTE HYDROGEN AS AN ALTERNATIVE FUEL

This presentation focuses on current and planned research and development efforts in the area of hydrogen use as a fuel for mobile and stationary sources in the South Coast Air Basin. It has been structured to provide background on regional air quality concerns and regulatory activity, particularly as they pertain to motor vehicles, as well as to respond to the specific questions contained in the March 1, 1993 invitation letter from the Subcommittee on Toxic Substances and Research and Development.

Introduction

Hydrogen, which has been used in space applications for many years, has long been recognized as the ideal, environmentally benign terrestrial fuel. It does not contain the carbon atom--resulting in near zero or zero air pollution when converted to power--and its supply is effectively inexhaustible. The South Coast Air Quality Management District (AQMD) commends and congratulates this Subcommittee for investigating how America can accelerate the introduction of hydrogen and other inherently clean fuels into the market for wide-scale use. Given the severe air pollution problem in the Los Angeles Basin, we are very pleased to have this opportunity to request greater participation from the federal government in our efforts to promote hydrogen. We see strong potential for expanded use of it in a wide variety of transportation and non-transportation applications involving internal combustion engines, fuel cells, turbines, and other technologies.

Background

The South Coast Air Basin (Basin) is a 6,600 square-mile area bounded by the Pacific Ocean to the west and the San Gabriel, San Bernardino, and San Jacinto mountains to the north and east. The Basin includes all of Orange County and the non-desert portions of Los Angeles, Riverside, and San Bernardino Counties.

The population of the Basin currently exceeds 13 million, with approximately 9 million motor vehicles registered in the region. Because of this high population and vehicle density, the Basin is the world's number one market for gasoline and is particularly vulnerable to air pollution. The topography and climate of Southern California intensifies the effects of air pollution generated in the Basin. Summer months are typically characterized by an inversion layer which inhibits the upward dispersion of air pollutants and results in the trapping of the pollutants. In addition, calm breezes during the summer further limit ventilation. The region experiences more days of sunlight than any other major urban area in the nation except Phoenix, increasing the potential for the photochemical formation of other pollutants, including ozone.

The Basin's principal air pollution concern is ozone. The Basin is also significantly above standards for particulate matter and carbon monoxide. Emissions from motor vehicles are a primary contributing factor to this problem. Specifically, on- and off-road motor vehicles contribute most of the ozone precursor emissions--approximately 50% of the reactive organic compounds (ROC) and 75% of the oxides of nitrogen (NO_x). These vehicles are also responsible for more than 90% of the carbon monoxide (CO) emissions and 6% of the particulate matter less than 10 microns (PM_{10}) produced in the Basin. Emissions of carbon dioxide, methane, and nitrous oxide, resulting from the combustion of fossil fuels, also contribute significantly to the greenhouse effect in which solar radiation is trapped by the earth's atmosphere.

Clearly, significant reductions in emissions from all sources, but especially from the transportation sector, are necessary in the fight to achieve healthful air in the Basin. Moreover, there is an urgent need to do so expeditiously. A recent study conducted for the AQMD by California State University found that the benefits of achieving the federal ambient standards for ozone and PM_{10} alone are at least $9 billion per year in the Basin.

Since the end of World War II, the Basin has experienced faster population growth than the rest of the United States. Although growth today is slowing somewhat, the region's population will continue to increase significantly. By 2010, it is estimated that the Basin's population will be approximately 18 million, representing more than a 50% increase from current levels.

Although per capita emissions have been brought down substantially in the Basin as the result of emission controls, increases in the population and vehicle trips over that time have made substantial overall emission reductions more difficult. Increases in the number of sources, particularly those growing proportionately to population, reduce the potential air quality benefits of new controls. The net result is that unless dramatic steps are taken to control air pollution at a much faster rate than ever before, growth will overwhelm the improvements expected from the existing control program.

The AQMD, as the regional regulatory body with responsibility for air pollution control in the Basin, is developing and implementing the world's most comprehensive air quality management plan for stationary and mobile sources. The AQMD is responsible for establishing and enforcing regulations for stationary sources and is actively involved in research to advance control technologies in this area, including several related to fuel cells and hydrogen generation. Efforts to control Basin vehicular air pollution are directed and enforced by state, regional, and local agencies, with the AQMD responsible for the overall clean up plan. The AQMD also funds, either partially or fully, mobile source research in emission controls and alternative fuels technologies for both on- and off-road categories. This funding includes several alternative fuel vehicle demonstration projects and research into fuel cell and battery applications.

The AQMD, in cooperation with the state and local agencies, has taken a comprehensive approach to reduce the impact of vehicular emissions. Goals of this strategy include: enforcement of existing standards; implementation of broader, more stringent emission standards; continued promotion of clean fuel vehicles and technology; and an increased emphasis on transportation control measures.

Because of the need to reduce emissions from mobile sources, the State of California's Air Resources Board (ARB) adopted regulations in 1990 mandating the production of low-emission vehicles for sale in the state. For the lighter vehicle classes, four standards levels have been defined by the ARB. Vehicle types based on the four standards levels, in order of increasing stringency, are transitional low-emission vehicles, low-emission vehicles, ultra-low-emission vehicles, and zero-emission vehicles (ZEV).

The ARB regulations establish ZEV sales requirements, as well as sales volume-weighted non-methane organic gas (NMOG) standards, starting with the 1998 model year. The regulations require that in 1998, two percent of each manufacturer's sales of passenger cars and light-duty trucks be ZEVs. In 2003 and subsequent model years, ten percent of sales of these vehicle classes must be ZEVs. At this time, only battery-powered electric vehicles and pure-hydrogen fuel cell vehicles will meet the ZEV definition.

It is anticipated that California will, in the near future, consider low-emission vehicle regulations for heavy-duty vehicles and urban buses. In addition, emission limits for California off-road vehicle classes such as construction and farm equipment, utility equipment, marine vessels, and locomotives are under consideration.

Responses to Questions

1. **What areas of environmental technologies are being developed in your area of expertise? Are they being developed in a timely manner and in conjunction with efforts in other areas of business and in coordination with appropriate federal programs?**

It is expected that wide-scale use of hydrogen will evolve in at least two ways. One path involves the development or modification of internal combustion engines to use hydrogen. Sometimes, to improve combustion characteristics or to lower costs, hydrogen is burned in combination with a fuel containing hydrocarbons (e.g., "Hythane," which consists of hydrogen and methane). From an emissions standpoint, hydrogen-fueled internal combustion engines will yield the greatest air quality benefits as they are optimized for pure hydrogen. The second scenario--involving electrochemical conversion of hydrogen for power through fuel cells--offers significantly higher efficiency with virtually no emissions. And, if pure hydrogen is generated through photovoltaic electrolysis of water and used in fuel cells, the result will be a truly zero-emissions technology, from cradle to grave, from an unlimited domestic resource--water.

The AQMD, through a world-leading public-private partnership, is pursuing a wide variety of research, development, and demonstration (RD&D) projects with an emphasis on advanced emission control technologies and alternative fuels. Some of the non-petroleum fuels that are focused upon include hydrogen, Hythane, renewable electricity, methanol, and natural gas. Details of the AQMD's RD&D program are summarized in the "Technology Advancement Office 1992 Progress Report, Volumes I and II," which have also been submitted for the record of these proceedings. It is important to note that, to restore healthful air quality to the Basin, maximum use must rapidly be made of the lowest-emission energy carriers: hydrogen and electricity. Key RD&D efforts by the AQMD and its partners involving hydrogen and renewable electricity include the following:

- Demonstration of America's first fuel cell in a commercial application. A 200 kW phosphoric acid fuel cell is now providing about 10% of the power at the AQMD's headquarters, with very low emissions.

- Demonstration of a solar-powered recharging station for electric vehicles. This project demonstrates the feasibility of true zero-emissions electric vehicles.

- Development and demonstration of America's first fuel cell/battery-powered urban transit buses. In conjunction with the Departments of Energy and Transportation, three near-zero-emission buses will be on the road this year.

- Demonstration of a solar hydrogen-generation plant in tandem with a hydrogen filling station for near-zero-emission vehicles. At the University of California/Riverside hydrogen is now being made from a directly coupled photovoltaic array. (The University and the AQMD benefitted from the assistance of Soviet scientists before the collapse of the Soviet Union which had advanced work in developing the use of hydrogen as a fuel.)

In addition to the visionary RD&D projects discussed above, the AQMD has been the catalyst behind formation of several key public-private organizations that are working to expedite hydrogen and fuel cell technology. These include:

- The Ad Hoc Coalition on Fuel Cells for Transportation, formed in 1992 by the AQMD as an advocacy group to facilitate the commercialization of fuel cells and related technologies for motor vehicle uses. This coalition works to promote U. S. fuel cells and related systems for mobile applications, both domestically and worldwide. A central objective is to procure more support from the federal government for fuel cell commercialization

- The Locomotive Propulsion Systems Task Force. Formed by the AQMD in 1992, the task force consists of major California railroads, locomotive manufacturers, fuel cell researchers and manufacturers, and regulatory agencies, including the U. S. Department of Energy. As a result of the task force's recommendations, the AQMD and others will be funding a feasibility and engineering evaluation of fuel cell technologies for locomotive applications.

In addition to the push on a technological front, California in general, and the AQMD in particular, has nourished important economic, regulatory, and institutional momentum towards sustainable, environmentally benign energy systems. For example, the following have been provided:

1. A favorable climate for the development of these technologies. Through adoption and enforcement of stringent environmental standards, California has stimulated a market for environmental technologies.

2. Incentives for businesses to buy and use these new products.

3. A clear linkage between environmental quality and policies that promote energy diversification and decreasing reliance on petroleum-based fuels.

Unfortunately, while California (as well as Germany, Japan, Sweden and other nations) has been demonstrating that these approaches can and do work, protection of the environment and energy self-sufficiency have been on the back burner in Washington. By often adopting progressively weaker requirements, the federal government has encouraged the development of dirtier, less-competitive technologies. The result is that in the

49 states other than California, environmental technologies are lagging badly. Air quality in other non-attainment urban areas could be immediately improved by adopting California vehicle standards and, thus, substantially reducing the burden on local industries and small businesses to make emission reductions. This simple expedient might allow some urban areas to achieve attainment with zero impact on their local economies.

2. What are some of the environmental benefits which would accrue from these technologies and how can these benefits be integrated in such a way that both the U. S. economy and the international economy might be more competitive?

As mentioned previously, the ARB low-emission vehicle regulations mandate the production of ZEVs for sale in California starting in 1998. The development of hydrogen technologies for on-road vehicles could provide an alternative to battery-powered electric vehicles for manufacturers to meet the ARB requirements. ZEVs fueled with hydrogen generated with renewable electricity would also provide a cleaner alternative to battery or hydrogen ZEVs using electricity generated through the combustion of hydrocarbon fuels. The low-emission vehicle regulations are expected to result in significant emission reductions in the Basin. For example, the ARB has estimated that by 2010, the implementation of the regulations will result in reductions of NMOG, NO_X, and CO of approximately 63, 95, and 110 tons per day, respectively.

The AQMD is in the process of developing a flexible market-based regulatory program in which permitted Basin sources could be brought into compliance with emission regulations through add-on controls, use of reformulated products, and/or by purchasing emission reductions from other sources. This "REgional CLean Air Incentives Market" (RECLAIM) represents a departure from traditional command-and-control regulations because it provides a greater degree of freedom to industrial sources in complying with air quality requirements. Businesses even turn a profit in doing so by generating excess emission reduction credits and selling them to others who find the purchase of credits less costly than installing controls.

Also under consideration for RECLAIM is a program in which credits generated through mobile source emission reductions could be used to offset stationary source emission increases resulting from industrial growth. One proposed scenario involves the generation of emission reduction credits through the purchase of ZEVs in excess of the levels mandated in the ARB low-emission vehicle regulations. This approach could mitigate restrictions imposed on industrial growth by air quality requirements, while increasing in-use fleet penetration of ZEVs.

Many cities throughout the world, particularly those in Eastern European and Third World countries, have extreme pollution problems. With rapid industrialization and as the standard of living in these countries improves, pollution levels are expected to worsen. Awareness and consciousness of the need for cleaner air in these countries will stimulate a major demand in the international economy for American-made clean air technologies. This already is happening in Taiwan and Mexico City, and the Megacities of the Pacific Rim are aggressively pursuing the economic as well as environmental benefits of these technologies.

Japan has formally adopted a policy to encourage products for domestic and international markets that are both energy efficient and ultra-clean. The United States must not be left behind. To compete worldwide, American companies need both fiscal and regulatory incentives from the federal government to develop clean air technologies.

In a recent policy address on the international economy, President Clinton said that there are 3 million people employed in export-oriented jobs. This number will, we believe, expand considerably IF American companies develop and refine zero-emission technologies such as hydrogen and fuel cell products for domestic and overseas markets. The federal government can and should be an active partner.

3. What are the current barriers to developing the technologies in your

area of expertise (e.g., legal, regulatory, institutional, lack of funding, incentives)?

It appears that the principal barriers to the commercialization of hydrogen-powered vehicles are technological, economic, and political in nature. In addition, public perception towards and potential demand for hydrogen vehicles is not known at this time.

Although hydrogen internal combustion engine vehicle prototypes have been demonstrated and research continues on producing fuel cell vehicles, neither technology is at a sufficiently advanced stage of development for commercialization. However, it is important to note that an experimental fuel cell bus is now on the road in North America, and several more soon will be. Factors such as fuel storage, range constraints, and safety also must be considered for hydrogen vehicles. One of the biggest barriers for hydrogen technologies is the lack of an adequate production, storage, and distribution network. Moreover, expanded use of hydrogen will require careful interaction with local officials such as fire marshals. It is important to note that these technological obstacles are not necessarily unique to hydrogen-powered vehicles, as they tend to plague most new fuel and technology applications.

With regard to economic obstacles, because hydrogen is at a very early stage of development as a motor vehicle fuel relative to conventional and other alternative fuels (e.g., methanol, natural gas, battery-powered electric), significantly more research funding is needed to bring hydrogen and fuel cell vehicles to a comparable level of development.

The political barriers are pervasive and magnified by the economic recession. This is particularly true in California, where an historic concern for environmental protection now has been surpassed by an even greater concern about the loss of jobs in our defense and aerospace industries, and the literally thousands of businesses that previously benefitted from this now-declining economic stimulus. This climate has permitted critics of environmental regulation to gain credibility with a concerned public and slow the transition to new technologies. The successful election campaigns of President Clinton and Vice President Gore did much to educate and excite the public about the economic and environmental promise and new technologies. But, unless this momentum is sustained, the unintended result of the critics of environmental regulation will be a U. S. economy dependent upon the stagnant and polluting technologies of the mid-20th century, while our international economic competitors in Japan and Europe race ahead to master and dominate the technologies of the 21st century.

4. What steps could be taken to reduce or remove these barriers and promote new research and development of commercially available environmental technologies?

Several steps must be taken to reduce or remove barriers to advanced environmental technologies involving hydrogen. First, because of the relatively early stage of development for such technologies, an order-of-magnitude greater research funding is needed to target development and demonstration projects. The federal government must take the lead and make a major funding commitment in this area. Second, infrastructural concerns--especially those involving vehicles--must be addressed in parallel with commercialization of hydrogen technologies. As an extension of this work, supplemental research into developing a hydrogen supply infrastructure, possibly utilizing existing natural gas pipelines, is necessary. This work will require close cooperation with fire prevention and safety officials. Finally, in order to enhance public awareness of applications such as fuel cells and hydrogen vehicles, funding of demonstration fleets and construction of pilot fueling facilities is suggested.

The AQMD supports the idea of creating and funding a National Hydrogen Implementation Board to oversee the development of hydrogen technology. Its members could be drawn from various participating groups such as governmental agencies, the academic community, and industry. Indeed, this Board might draw expertise from Russian scientists who have made headway in developing this technology and assisted our efforts in California. Vendor and end-user groups such as the petroleum, aerospace, automobile, and natural gas industries, as well as utilities, can participate by cost sharing. Together, they can help bring hydrogen technology to maturity.

The AQMD also supports the idea of funding a program involving a large-scale demonstration of fuel cell and hydrogen vehicles in the Basin. In such a program, a wide spectrum of hydrogen production, distribution, storage, and end-use technologies can be investigated and demonstrated. For example, the project could include design and evaluation of small-scale, distributed natural gas reforming stations, on-site hydrogen storage and dispensing stations, vehicle modification and design for on-board hydrogen storage, use of hythane as a transition fuel, and safety assessments of hydrogen.

5. If applicable, please explain if foreign investments in similar technologies have adversely affected U. S. competitiveness in the market area of your expertise and how you view the future of foreign competitiveness in the same regard.

To the extent that fuel cell technology will rely on hydrogen fuels, Japan, Germany, and, until recently the Soviet Union, have made considerable progress. At this time, it is unclear which manufacturers, foreign or domestic, will be in the best competitive position to manufacture and market ZEVs in California by 1998. Historically, the foreign competitors of U. S. industry have shown greater patience and persistence in developing new technologies. To our national embarrassment, foreign industries have reaped enormous profits from technologies abandoned by U. S. industries, from selective catalytic reduction on industrial smokestacks to the VCR near your color television. The fuel cell was advanced at a high cost by NASA but it is being aggressively developed elsewhere for commercial applications, such as in cars and buses. Similarly, hydrogen is being aggressively pursued elsewhere. While we cannot now predict whether foreign manufacturers will adversely affect U. S. competitiveness, it is noteworthy that the current leaders in hydrogen vehicle technology--Mazda, BMW, and Mercedes Benz--are all foreign companies. Recent history does not give cause for comfort.

Conclusion

The South Coast Air Quality Management District and its fellow California regulatory agencies have made a major commitment towards expediting commercialization of the most environmentally benign fuels and technologies. Healthful air quality cannot be re-stored to the Basin without wide-scale implementation of zero-emission technologies using some combination of hydrogen and electricity as the energy carriers. California's efforts are focused to make this transition as rapidly as possible through a combination of visionary regulatory actions and a widely recognized public-private technology advancement program, spearheaded through the AQMD.

By contrast, for the past dozen years the Executive Branch of the United States government has been indifferent, at best, to the development of environmental technologies, including ways to produce and use hydrogen. Transportation fuel cells have been a particularly short-sighted low priority for the federal government. The AQMD strongly advocates major increases in the hydrogen and renewable energy research and development budgets of the Departments of Energy and Transportation. This is the single most important action that can be taken towards a sustainable environmental and energy policy for the United States.

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UNITED STATES SENATE

COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS

- Hearing on Hydrogen -

Senate Dirksen Office Building
Washington

March 22, 1993

Contribution of
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Introductory Remarks:

The statements given in the following are often selective and not completely balanced since given from a certain point of view and they do not claim to be complete and exhaustive.

In general the statements given start out from the German situation and conditions and then try to extend the view on European conditions, and where indicated also on the situation in other countries.

Furthermore, when reflecting on the statements given it may be worthwhile to know that also in Germany, like in most pluralistic societies, no consensus on sustainability of energy generation and utilization does exist yet and that many contradictory positions prevail in public, on political level and in industry. Though, a wide consensus exists on the necessity for CO_2 reduction or at least stabilization.

The questions raised are answered to the best of knowledge and understanding.

What areas of environmental technologies are being developed in your area of expertise? Are they being developed in a timely manner and in conjunction with efforts in other areas of business and in coordination with appropriate federal programs in other countries?

Technologies developed in area of expertise:

My area of expertise extends on system engineering, management of renewable energy projects and evaluation and technology assessment of such systems, especially in the following technologies:

- Photovoltaic Systems
- Solar Thermal Systems
- Wind Energy Converters
- Electrolysis
- Fuel Cells
- Hydrogen Application Technologies
- Hydrogen Storage and Handling Technologies
- Hydrogen Vehicles
- Hydrogen Airplane

Developed in a timely manner or not:

The question if these technologies are developed in a timely manner is very difficult to answer since it depends very much on the concept approach one may have of the energy economy.
Furthermore, the term 'developed' has to be defined in order to clarify if only the basic research and development is understood or also its demonstration and its preparation for large scale fabrication.
In the following, under the assumption that renewable energies and hydrogen shall be developed to a real alternative of present conventional energies consequently, the timely development shall be assessed.

Photovoltaic Systems: The present world production of all PV technologies lies in the order of more than 50 $MW_{p,e}$ annually having a sales volume of approx. 375 MECU. In Europe some projects in the Megawatt scale are under way; a 1 MW plant in Spain, a 3 MW plant in Italy (as part of 50 MW to be built until the year 2000) and in Germany about five PV plants of the 300 kW size are in operation and in Bavaria an electric utility plans to install a total of 3 MW until the year 2000. Although PV sales are growing with a rate of about 25% per year, compared with regular utility scale applications no significant quantities are being produced presently or will be produced even in the year 2000 if the market is not pushed by incentives or developed systematically. To change this situation, i.e. to achieve much higher market penetration, at a given time always the best technology (with the best cost benefit ratio) should be produced at large scale and brought to the market (at the beginning certainly to a subsidized market). By the experience gained in these applications, also the balance of system costs will be reduced gradually. When one production plant is depriciated, the next best PV technology will enter into large scale production and will be advanced in a similar way. By following this approach a significant cost reduction and market penetration can be achieved. The first large scale markets could be grid connected roof top mounted applications in industrial countries and various applications in developing countries within development aid programs.

Wind Energy Converters: Wind energy converters of small (< 300 kW) and medium (< 1000 kW) power output are already far developed and can provide electrcity at reasonable costs (10 $cents_{US}$/ kWh_e). To be successful with wind energy at a larger scale in the future also in more densely populated regions such as Europe, it seems worthwhile to develop also large sized wind converter of about 3 MW_e power output. Some RD&D efforts will be necessary for these converters in order to bring them successfully into the market.

Solar Thermal Systems: When considering solar thermal energy conversion technologies one has to differentiate between two basic approaches, flat plate and concentrating solar thermal collectors for hot water production and concentrating solar thermal conversion systems for the production of process steam for the generation of electricity.
The systems for hot water production under certain conditions can be economic in Europe. Even in Sweden, solar thermal district heating for e.g. condominium or appartment complexes are economic. Solar thermal heating of hot water in single houses is not yet economic in central Europe due to low fossil energy prices.
Solar thermal electricity production with parabolic trough technology can be economic under very special conditions (as the ones which exist/ did exist in California) and south of 40° latitude. This technology can be improved in efficiency and economics when replacing thermo oil as energy carrier by water vapour in direct evaporation concepts. As soon as industry would see a market for large scale applications anew it would pay for the necessary R&D to commercialize this system.

Electrolysis: Electrolysis technologies in conjunction with hydro-electricity are in operation since more than 60 years and were developed further step by step. The requirements for electrolyzers to be coupled with fluctuating renewable energy resources such as wind or solar are more ambitious than those for hydropower applications. Still not enough experience does exist in this field and sufficiently cost effective systems have to be developed. Such activities are presently undertaken at various research centers and companies especially in Germany and are regarded to be of high importance for the realization of solar hydrogen energy concepts at large scale. Therefore, present RD&D activities have to be maintained at current levels to ensure a consistent advancement of this technology.

Fuel Cells: For the efficient and environmentally benign conversion of hydrogen into electricity fuel cell systems seem to open very promising perspectives. This especially seems valid in the case of vehicle propulsion. For this field of application membrane fuel cells seem to have the best chances. Presently worldwide only very few membrane fuel cell systems have been developed and successfully tested (e.g. Canada, USA, Germany, Russia). Therefore, besides the improvement of the cell membrane and the stack technology and cost the advancement of the system technology (process, control) and of the manufacturing technology are the most important issues.
Most European activities in the field of fuel cells (phosphoric acid FC, molten carbonate FC, solid oxide FC, membrane FC) are based on US technology and further developed.

Hydrogen Application Technologies: Among these technologies count e.g. large scale industrial burners for boiler power plants, catalytic diffusion burners/ heaters, H_2O_2 steam generator for spinning reserve, stirling engines, gas turbines, gas and steam turbine processes, internal combustion engines for stationary applications (external or internal mixture formation), hydrogen/ methane premix burners, etc. (the technologies treated in detail in this paper are not mentioned here). A general statement to hydrogen application technologies concerning the timely development cannot be given in general due to the diversity of these technologies. Some of the technologies are already state of the art (e.g. industrial large scale H_2 burners), others are close to economic application (e.g. pilot demonstration of H_2O_2 steam generator for spinning reserve) whereas many are still in development or testing stage.

Hydrogen Storage and Handling Technologies: In parallel to the development of hydrogen application technologies also the concepts and technologies for the handling and storage of hydrogen have to be developed and tested, such as transport containers for road, rail and ship, pipeline systems, conversion technologies, refuelling stations, small mobile and large stationary storage concepts and safety components, in order to ensure the timely availability of these infrastructural components. Various activities are under way in Germany and Europe.

Hydrogen Vehicles: For one decade hydrogen powered passenger cars and vans with internal combustion engines have been developed and tested extensively in Germany. As storage concepts metal hydrid and liquid hydrogen storages were used. Currently also the first public city buses with internal combustion engines and with fuel cells as power sources are in development for demonstration purposes and shall be tested middle of the 90ies. If one accepts the goals of emission reduction especially in civic centers as serious ones, and if one considers the lead times in technology development necessary to come to licensed and approved vehicles, and if the present efforts are maintained and on necessity increased, then these activities seem to run in a timely appropriate schedule.

Hydrogen Airplane: In Germany concept studies are carried out on the modification of an Airbus airplane to be operated with liquid hydrogen and/or natural gas since some years. These studies are carried out jointly by German and Russian companies and institutions and are funded by German industry and German Ministry of Economics. Hardware modifications on jet engine combustors to be tested with hydrogen are under way in a joint German/ Canadian EQHHPP project funded by industry and by CEC and Québec Government. Present goal of the German industry is to be prepared (i.e. having tested a demonstrator airplane and be capable to go into series production) for series production and to start market introduction around the year 2010. Taking into account that the average lifetime of an airplane is around 25 years, this goal does not seem too optimistic.

In conjunction with other areas of business:

Photovoltaic systems traditionally have profited from micro-electronics development and process engineering, but not to the extent originally assumed 20 years ago.
Presently PV cells are not only integrated into conventional modules but also into building facade elements. Thus on one side the development of the facade concepts is influenced by PV technology and receives an innovative push, on the other hand the manufacturing and configuration of PV cells is modified or optimized for such applications.

Solar thermal flat plate collector systems increasingly are developed in conjunction with improved systems for domestic space heating. The most recent developments, such as tranparent insulation systems, originally aimed at improved heat insulation and passive solar heat recovery for sun oriented building walls and then were also employed for significantly improved solar collector systems.

Wind energy converters in some cases were spring-offs of diversification programs of ship yards. Also in Germany one very successful manufacturer of wind converters comes from ship building. Even broader perspectives will be opened when wind converters will be installed off-shore in shelf areas of the German North Sea or the Baltic Sea permitting the utilization of large wind potentials.

Electrolysis development for many years profited from the development of chlorine-alkali-electrolysis employed at a large scale in chemical industry for chlorine production.

Fuel cells as an electricity generating device with a very good mass to power output ratio were pushed ahead in their development by manned space undertakings, by submarine propulsion applications and by remote military applications in the last three decades. In order to come to a more continuous development of fuel cell technologies it is important to open new fields of application e.g. in the utility and transportation sectors. Due to fuel cells being an electrochemical technology they also have taken advantage of the knowledge accumulated in the R&D and application of electrolysis technologies.

Many *hydrogen application technologies* can participate in the knowledge acquired in the development of natural gas concepts, such as catalytic burners and heaters do from catalytic converter knowledge accumulated in the safety equipment design for nuclear power plants, and cogeneration and vehicle applications partly do from the development of natural or petrol gas engine development.

Hydrogen Storage and Handling Technologies especially for liquid hydrogen (e.g. liquefaction plants, cryogenic containers, cryo-pumps) were developed and brought into practical use during the last three decades due to the necessity to transport clean, cryogenic hydrogen to various consumers, such as the micro electronics industry, as well as due to the major liquid hydrogen consumer which is high performance rocket propulsion. Beyond transport distances of several hundred kilometers hydrogen can be transported economically only in liquid form. Cryogenic components development profited from helium cryogenic development for collider experiments.

Hydrogen airplane development can partly profit from developments (to be) carried out in the field of emission reduced (low NO_x, HC) kerosene jet engine combustors as well as from knowledge accumulated in space programs.

Safety concepts for hydrogen application mainly were developed in conjunction with space programs (NASA safety handbook) and nuclear reactor engineering, as well as for former utilization of hydrogen rich town gas.

Job conversion aspect:

Already in recent years many industrial companies active in space technologies and in defense industry started to diversify into the sector of environmental technologies. Therefore, in many of these businesses besides the knowledge on combustion processes, on materials research, on system engineering, on the handling of complex projects, already experience exists with respect to envrionmental concepts which can be used for the extension into renewable energies/ hydrogen technologies.

Such a transformation approach has to pay a very close attention to stringent cost conditions valid for commercial industries which did not exist to such an extent in space and defence industry. A very effective cost management is essential, otherwise a conversion approach will not be successful.

Furthermore, diversification strategies into the field of hydrogen technologies should be complementary to already existing industrial activities, not competitive, in order to allow utilization of synergetic effects. Existing industrial activities are electrochemical applications, hydrogen storage, handling, conditioning and distribution for industrial uses (food, glass, electronics,etc.), safety equipment, and others.

Coordinated with appropriate foreign programs:

BMFT (German Ministry for Research and Technology):

The total RD&D budget of the BMFT reaches some 9.6 billion DM in 1993.

The departments 311, 312 and 313 within the BMFT are responsible for:
- basic and planing issues in energy research and technology and rational energy use (311),
- solar energy and renewable energies (312) and
- wind and geothermal energies, hydrogen technology and energy storage technologies (313).

The BMFT budget for renewable energies, rational energy use and energy storage as well as hydrogen amounted to 288 million DM (1992) [the total federal R&D budget for this area amounted to a total of about 320 million DM in 1992]. In 1991 and 1992 some 20-24 million DM were devoted to hydrogen annually. Out of this federal funding some 4.5 million DM (35%) went into the SWB solar hydrogen project budget of 13 million DM annually since 1987 (15% were cofunded by the Bavarian government, completing a governmental funding ratio of in total 50%).
In the BMFT budget R&D in the field of renewable energies and rational use of energy have a share of approximately 3%, whereas nuclear fission and fusion R&D have a share of almost 10% together.

In the field of hydrogen coordinated approaches exist on the basis of the funding of international projects. Some selected examples are highlighted in the following:

- The project HYPASSE (1990-1994/ 1995-1998) between Germany and Switzerland focuses on hydrogen as short term and seasonal storage to be applied in buses.
- The HYSOLAR project (1985-1995) which is carried out by Germany and the Kingdom of Saudi Arabia jointly, focuses on photovoltaic solar hydrogen production and on related R&D and training programs.
- In the field of molten carbonate fuel cells a Danish / German consortium has been set up by technology and utility companies to carry out a RD&D and pre-commercialization program (1990-1997). The funding is provided by the participating companies, by BMFT and by the CEC-THERMIE program. The basis for the development is a licensing agreement with a US technology partner.
- In the investigation 'Norwegian Hydro-Energy for Germany' [NHEG] (1990-1992)

the hydro-hydrogen production in Norway, its handling and maritime transport, and its distribution in Germany were investigated in a case study and evaluated against alternative technologies and energy transport vectors. The funding was provided by the BMFT, the CEC, the Norwegian Government and by industry.

In the field of renewable energies most CEC funded projects require at least partners from two EC countries thus encouraging inter-EC cooperation. BMFT in some cases also funds bi- or multinational cooperations in order to coordinate research goals and to improve funding budget efficiency. As one example, also for many other renewable energy activities, may stand the presently largest PV project which is a grid connected 1 MW PV plant in Spain, jointly built and operated by German (RWE Energie AG) and Spanish (Unión Eléctrica Fenosa SA) utilities and organized under EUREKA EU 726 Toledo PV-1 project frame.

Commsission of European Communities:

EUREKA Σ!:

- mainly competitive programs, some also in basic R&D
- cooperation possible with 20 partners form the EC, EFTA and Turkey
- no general plan is necessary
- program launched in 1985
- the overall budget is more than 8.1 billion ECU
- 2700 participants, 1765 from larger companies, 469 small and medium size companies. 785 research institutes and universities (23 participants from non-member countries, 9 of them from non-European countries)
- if and how much will be funded is to be decided by national governments (presently projects of a total of 1 MECU are active)

[besides HDTV and JESSI also a multinational hydrogen fuel cell bus project (EU 201) is carried out by Ansaldo, Air Products, Elenco and Saft over a period of 6.5 years with a budget of 4.25 MECU]

BRITE/EURAM (Industrial and Materials Technology Program):

- areas covered:-materials and raw materials, design and fabrication, aviation
- objectives: redynamisation of European processing industry by support of basic R&D, development of advanced technologies and technology transfer; integration of

small and medium sized companies into international research

- the overall budget is 663.3 MECU over the period 1991/9/9 - 1994/12/31
- funding support by EC of up to 75% and at maximum 30,000 ECU

JOULE II:

- areas covered: analysis of strategies and modelling, minimum emission power production from fossil sources, renewable enrgy sources, geothermal energy and deep reservoir geology, energy utilization and conservation .
- objectives: contribute to the development of new energy options that are both economically viable and envrionmentally safer, including energy saving technologies
- the overall budget is 138 MECU over the period 1991/9/9 - 1994/12/31
- battery driven vehicles shall be developed in cooperation with EC programs SAVE, THERMIE and Industrial and Materials Technology Program and together with the Belgian CITELEC program

[renewable energy sources focuses on the solar house approach, renewable power plants (wind, PV, tidal power), biomass, renewable energies for rural electricity, local fuel and water

energy utilization and conservation focuses on fuel cells (large scale application MCFC, SOFC/ small scale and vehicle application fuel cells such as SPFC and DMFC for the fuels methanol, methane and hydrogen), technologies for energy saving in industry and buildings, energy efficiency in transport including suitable substitutes for conventional fuels (combustion and fuel cell and battery driven electric vehicles]

THERMIE:

- areas covered: rational energy utilization, renewable energies, solid fuels, hydro carbons
- objectives: support of demonstration and pilot activities in the field of new energy technologies which shall advance these technologies to the level of practical application and reduce the risks related with their realization
- the overall budget is 350 MECU over the period 1990 - 1992, total program duration is 1990 - 1994

VALOREN:

- areas covered: utilization of local energy resources (renewable sources, small peat and lignite sources), rational energy use in small and medium size industry, better utilization of energy potentials on local and regional level

- objectives: strengthening of economic situation in structurally weak regions within the EC by the improvement of the local energy supply
- the overall budget was 392 MECU over the period 1987 - 1991 and the support was effected in investment or interest subsidies for grants mainly devoted to public and regional bodies

EQHHPP:

The Euro-Québec Hydro-Hydrogen Pilot Project (EQHHPP) is to demonstrate the provision of clean and renewable energy in the form of hydrogen obtained from already existing 100 MW of Québec hydro-electricity via electrolysis, its conversion into liquid hydrogen, its maritime transport to Europe where it shall be stored, distributed and used in various applications: vehicle propulsion, aviation, electricity/ heat co-generation and hydrogen enrichment of natural gas.

The different activities are carried out by industry/ institutions and are separately funded by CEC on a cost shared basis but not within existing regular CEC programs. Joint EQHHPP projects between Europe and Québec are also co-funded by the Québec Government. Accumulated project budget (contracts signed) is about 45 MECU. Among others, one of the objectives of the EQHHPP is to promote R&D, to facilitate technology transfer and to stimulate industrial cooperation. The CEC money does not come from regular CEC programs such as JOULE or others, but is money applied to at and received granted by the European Parliament from annual R&D funds not allocated in the regular CEC programs. In conjunction with Phase II activities also a smaller supplementary hydrogen R&D activity was started which was cofunded by the German BMFT.

European Parliament Committee on Energy, Research and Technology:

The European Parliament Committee, having regarded among others the following three motions for resolutions in context with renewable energies brought up by parlamentarians

- the motion for a resolution B3-1686/90 which called for creating an independent 'European Association for the Promotion of Renewable Energies' with the aim of far-reaching research, development and demonstration of renewable energies with financial support from the Community, the Member States and third countries and a therefore recommended close cooperation between the Community, industry and research institutions;

- the motion for a resolution B3-0726/91 which called on the Commission to submit proposals without delay for financial support for wave energy research and for corresponding demonstration projects;

- the motion for a resolution B3-1732/91 which called on European Community efforts to be stepped up to use agriculture and forestry by-products as a source of energy and to produce biomass from special fast-growing crops and proposes that the European Community should step up biomass production for industrial and energy uses

filed a motion for a resolution on the promotion of renewable form of energy (A3-0405/92) in December 1992.

Among others, this motion for a resolution calls for the setting up of a 'Directorate for Renewable Forms of Energy' which shall consist of the six departments: direct solar energy / energy from biomass / wind, sea, and water power / energy storage and hydrogen / rational use of energy, dispersed energy, and combined energy production / energy, environmental, and econometric models.
Furthermore, the opinion is expressed that the forthcoming fourth framework program of the Commission should center on 1. precompetitive technological development (e.g. including also hydrogen technology), 2. specific future applications development and 3. support programs and should be organized under two budget headings, one called FUTURE (Future Technology Undertakings for Renewable Energies) and the other called ENTEC (Energy Technology Program). FUTURE shall contain 250 MECU for demonstration in the field of renewable froms of energy.

Canada:

Canadian activities in the field of hydrogen related RD&D give emphasis on basic R&D and studies (e.g. separators, catalysts, refrigeration) for electrolysis, fuel cells, liquefaction and on first small scale fuel cell applications. Renewable hydrogen from hydropower is produced by water and chloralkali electrolysis at Becanncour in Québec and commercially available as liquid hydrogen at a capacity of about 10 t per day since 1987.

Japan:

Under the framework of "The New Earth 21" program in Japan the New Sunshine Program tries to give a comprehensive approach for sustainable growth by a simultaneous solution of energy and environmental constraints, The program consists of three subdivisions which are the:

- *Innovative R&D Program* [¥ 500 billion between 1993 and 2000] covering innovative technologies essential for the achievement of stabilization of CO_2 emissions per capita at 1990 levels in the year 2000.
- *International Collaboration Program for Large R&D Projects* [¥ 900 billion between 1993 and 2020] aiming at the initiation of large international R&D projects contributing significantly to greenhouse gas reduction.
- *Cooperative R&D Program on Appropriate Technologies* [¥ 150 billion between 1993 and 2010] aiming at development and assimilation of appropriate technologies in neighboring developing countries through cooperative R&D apporaches.

Within the 'International Collaboration Program for Large R&D Projects' the *International Clean Energy Network using Hydrogen Conversion (World Energy Network WE-NET)* is foreseen. The WE-NET system shall make use of renewable energy sources such as solar energy, hydropower and wind energy by converting the electricity generated into hydrogen via water electrolysis. The hydrogen converted into transportable and storable form (synthetic fuels, liquid hydrides or liquid hydrogen) shall be transported via containerized maritime transport to the places of demand. There it shall be used in the utility and transport sectors. International cooperation is regarded as a key factor in the realization of this concept.

Within this approach, basic research is planned for the period 1993-2003, pilot plant operation for the period 2003-2020, the implementation of practical use for the period 2020-2030, and the worldwide commercialization is foreseen after the year 2030. The total estimated budget for the hydrogen activities in the 27 year period 1993-2020 is 300 billion ¥ (approx. 2.5 bill. US$).

As first steps Japan seems to negotiate the delivery of 4,000 MW of hydrogen from Canada and to prepare for the build up of the necessary infrastructure for the operation of hydrogen vehicles still in this decade.

High priority presently have phosphoric acid fuel cells, photovoltaics and wind energy.

Until the year 2000, PAFC fuel cell cogeneration plants operated with steam reformed hydrogen coming from natural gas shall reach an installed capacity of between 1,000 to 2,000 MW_e (depending on the information sources). For the year 2000 some 250 $MW_{p,e}$ of PV shall be installed in Japan, where presently only 50 $MW_{p,e}$ to be installed by the electric utilities are agreed upon. For 2010 some 4,600 $MW_{p,e}$ of PV shall be operative in total. To achieve these goals as set up by MITI and partly by Japanese electric utilities several production facilities of 100 MW_p annual capacity have to be in operation in the late 1990s. In 2010 more than 5% of the final energy demand shall be covered by new energy technologies, i.e. fuel cells, photovoltaices and wind energy.

What are some of the environmental benefits which would accrue from these technologies and how can these benefits be integrated in such a way that both the U.S. economy and the international economy might be more competitive?

Environmental benefits accrued:

Renewable energies as well as renewable hydrogen contribute to the reduction of local and global emission levels since they can avoid the emission of nitrogen oxides, sulphur oxides, carbon monoxide, hydro carbons (including methane) and last but not least carbon dioxide completely or almost completely, depending on the applied technical concept.
These technologies furthermore have significantly reduced accident potentials and impact levels in cases of accident (e.g. no oil spills).

Improved competitiveness by an integrated approach:

Renewable energies as well as renewable hydrogen presently are more expensive than conventional polluting fossil energies and fuels. On the other hand it can be assumed that most renewable energies will become cheaper by widespread application whereas conventional energy carriers will suffer from a steady cost increase due to pollution mitigation or prevention costs as well as at the long run from depletion costs. To overcome the presently unfavorable situation for renewable energies and hydrogen first niches of application should be supported, either by subsidies limited in time or by regulations favoring clean concepts. Such subsidies, e.g. could be granted for a certain output depending on the profit per unit achieved thus providing an incentive for minimizing production costs. Out of the niches created the environmentally more compatible technologies can evolve step by step and become commercially competitive technologies.

Such niches, as e.g. created in the transport sector by the zero emission and ULEV requirements for vehicles in California, should be initiated worldwide in major polluted urban areas and explored by pilot and demonstration projects. Hereby the implementation of clean technologies can be achieved locally and by optimum adaptation to given boundary conditions.

Furthermore, the instrument of energy taxes (not CO_2 taxes, because too selective) on conventional, non-renewable energy technologies to be imposed worldwide or within larger market systems (EC, NAFTA or OECD) and in a step by step approach could support the

market penetration of renewable energies at large scale.
Internationally active banks and industries are requested to develop efficient regulatory and financing instruments in order to facilitate the construction and operation of large scale renewable energy generation systems. Long-term purchase contracts for renewably produced electricity including take-and-pay agreements could reduce investors' risks.

What are the current barriers to developing the technologies in your area of expertise, e.g., legal, regulatory, institutional, lack of funding, incentives?

Lack of funding:

Funding for renewable energy research and development during the last two decades has been at least one or two orders of magnitude smaller than that for conventional fossil or nuclear energy technologies. Even in Germany where the situation was not the worst one, in the development of nuclear energy technology went more than 30 billion DM government funds (accumulated over the last 30 years), whereas into the R&D of renewable energies and energy conservation since 1974 only some 2.5 billion DM. At least similar or even more unfavorable is the ratio of funds raised by industry. Nevertheless German government was one of the biggest governmental supporters of renewable energy technologies worldwide, especially funding basic scientific research.

Incentives:

The build-up of wide spread renewable energy infrastructures (renewable electricity and hydrogen) at the beginning (when these technologies are still comparatively expensive and the economies of scale are not yet effective) will require significant governmental support. No harmonized approach or framework on incentives for the accelerated implementation of renewable energy technologies and energy conservation measures does exist in Germany or in Europe.

Institutional barriers:

With respect to governmental funding in Germany, requests for increased industrial self-contribution in federally funded R&D programs (e.g. in Germany) are justified in single technologies close to economic application (e.g. flat plate solar thermal collectors, small wind energy converters, some systems for biomass utilization, small PV systems, etc.), but are not justified for systems/ technologies which are still far away from today's wider use in energy economy (solar electricity generation, large scale PV, large wind energy converters, electrolysis, fuel cell).
The fluctuations in governmental funding from one crisis to another crisis in the energy supply system make it very difficult to maintain successful development lines or to keep R&D teams together. Continuity in funding therefore can serve as a suitable incentive for

industrial research at medium and long term.
Not enough non-governmental institutions are yet active in the funding and in dissemination programs for renewable energy technologies.

Regulatory barriers:

In the special case of hydrogen existing codes and regulations usually do not include or reflect hydrogen as a product itself. This refers to most national gas codes as well as to international codes as e.g. those on the maritime transportation of liquid gases as ruled by the International Maritime Organization (IMO) in London which include only liquefied petroleum gas (LPG) or liquefied natural gas (LNG) but not liquefied hydrogen (LH_2). For a successful and efficient planning and design process for a new technology or concept to be applied on a worldwide basis an extension of such codes to the technology or concept in question is mandatory.

Legal barriers:

In Germany the presently existing law regulating the duties of utilities [Energiewirtschafts-gesetz', 1935] requests to produce energy as reliable, safe and economic as possible. Not as environmentally compatible as possible. In remunerating renewable electricity the most recent federal decree on electricity rates [BTO Elt] takes into account only avoided costs. Furthermore the utility business is maintained in a monopolistic structure which does not ensure sufficient competition and flexibility. Still private consumers are subsidizing industrial electricity rates.

What steps could be taken to reduce or remove these barriers and promote new research and development of commercially available environmental technologies?

How to reduce the barriers:

For a successful introduction of renewable energy source and hydrogen we first of all need the perception and the conviction for the need of a sustainable and environmental compatible economic and especially energy system. In order to give renewable energies and hydrogen a chance and to promote their wide spread application it is a prerequisite to artificially increase relative energy prices. The very often cited argument that Germany would loose its international competitiveness seems of a weak kind, since in the average German industrial product costs the energy cost share contained amount to not more than 4 %.

Incentives: Reduction of barriers can be achieved either by mandatory regulations or bans or by a system of incentives, such as subsidies, tax privileges, energy taxes, emission duties or certificates. For technologies or concepts which are rather close to economics (better thermal insulation techniques in new buildings, solar thermal hot water production, wind energy) it may be helpful to impose mandatory regulations/ bans as e.g. in the case for thermal protection of buildings. For the tapping of more costly renewable energy potentials (direct solar) limited direct subsidies, emission taxes, emission duties and emission certificates can be appropriate instruments.
Direct subsidies, limited in time, may be especially helpful for the introduction of technologies which at the time of market introduction are often suffering from high costs due to insufficient utilization of production capacities (as observed e.g. in the case of photovoltaics). These subsidies on investment costs will phase out when the economies of scale and the cost reduction start functioning. Such supporting subsidies should be accompanied by education and training programs for craftsmen and private industry.
If energy taxes are to be applied in supporting the market introduction of renewable energies substituting fossil energies, these taxes should be increased step-wise to such a level which within an assumed scenario would take also into account the most expensive renewable energy alternative considered.
In order to cover the additional investment costs and / or assumed risks, guaranties could be given to banks which then could finance renewable energy projects on existing commercial conditions. These guaranties could be granted by special institutions, such as foundations or eco-funds.
Loans with long durations and probably reduced interest rates (as in the case of mortgages)

should be brought to the market in order to easen the access of investors which want to become active in the renewable energy business.
In the case of the application of energy duties the advantage would lie in the fact that the funds raised can be devoted to the goals of the duty and that the amount raised decreases when approaching the level of emission reduction aimed at. Disadvantage of duties in comparison to taxes is that the government has to invest higher administrative efforts in order to decide which projects should be funded. Such decisions, as also in the case of direct investment subsidies, are taken mostly on the basis of an incomplete information situation. Additionally, in the case of public budget deficits the temptation prevails to handle duties as taxes, thus even less justifying the higher administrative efforts.

Considering a global approach it may worthwhile to start with large scale renewable energy projects in regions favored by good meteorological boundary conditions (e.g. high insolation). Many of these areas lie in developing countries.
Between many industrial and developing countries financial agreements/ protocols exist which should be used in order to reduce the investment costs of the most economic renewable energy generating technologies (often 20-30% higher than conventional plants) to be implemented in these developing countries on the investment costs of the competing local fossil energy (coal or oil).
Although requested by World Bank since at least two decades, in the majority of these countries energy prices are not yet covering generation costs. This would put the local utility in the position to accumulate the capital necessary to invest in modem generating infrastructure thus improving efficiency and overall economics. By this also a more favorable remuneration of the electricity produced would be achieved. On the other hand this in most cases would not be sufficient to attract enough capital for renewable energy projects. Therefore, the international development banks should consider internal rules/ orders which in future favor environmentally compatible energy generation (e.g. CO_2 reduction approach taking into account costs for avoided tons of carbon).

In industrialized countries which have decided on national reduction schemes for energy related greenhouse gases such as CO_2, industry should be allowed to receive bonuses on an account established by the national governments and to depreciate its investment, also when avoiding these greenhouse gases by implementing renewable power plants in other, e.g. developing countries. Such a gradual CO_2 compensation strategy would allow the domestic utility much easier to raise the capital and to depreciate its investement. The money necessary for such increased depreciation measures should be raised by domestic CO_2 taxes or duties.

Besides international cooperation in general, another apporach could be the establishment of an international environmental fund into which a certain part of the money raised by CO_2 taxes/ duties should be invested. The fund should support an environmentally compatible and sustainable energy generating infrastructure in developing countries, mainly focusing on rational use of energy and on renewable energy technologies. Also this approach requires a minimum of common understanding about global goals for a sustainable development also in the energy sector and about a transfer of capital into such areas. Otherwise it certainly would be very difficult if not impossible to convince developing countries to enter into international CO_2 reduction measures.

By the European Community a CO_2 and energy tax is discussed since some time which would lead to an ecological reform of the European taxation system. In average each barrel of oil consumed should receive a levy of US$ 3, increased by 1 US$ per year until reaching US$ 10 in the year 2000. Coal would be taxed higher due to its highest CO_2 emissions of all fossil energies, nuclear energy and large hydropower would pay only half of this amount, but would pay energy taxes for conservations' sake. Solar energy and other renewables would pay no taxes at all.

In Germany widely (but also controversely - mainly by industry) discussed is an approach which calls for steady (and thus reliably foreseeable) tax increases of nominally 5% per year to be imposed on consumer energy prices (thus leading to a more realistic price level especially in the transport sector). This reform in general aims at a better internalization of external effects of energy use by increasing taxes on depletable resources and on the other hand would call e.g. for a reduction of taxation of labor and capital, thus not increasing the tax burden in total.

The trade with international emission certificates requires international control bodies. This presently seems difficult to realize on a global level since it would require the delegation of national rights to international bodies, i.e. a loss of national sovereignty.

The *eco-bonus approach* in general is characterized by an artificial increase of the price of a product or commodity used within a closed system such as a plant, an industrial company, the transport system, etc. All participants in such a system pay a certain levy per unit consumed into a fund. Each player is reimbursed from this fund either equally or in relation

to the number of units consumed, depending on the optimization criteria applied. The system has net-payers and net-receivers, which can determin their role within the boundaries established. With respect to overall costs incurred in the defined system, the system is neutral. The administrative costs are minimal.
As an example may serve the road transport sector. In order to achieve e.g. a higher fuel efficiency the fuel price is increased artificially. The money raised goes into a fund. The reimbursement is done on the basis of the distance traveled in the annual tax declaration as already handled today. In order to achieve e.g. a higher fuel efficiency and a structural change in the transport sector the fuel price is increased artificially. The money raised aslo goes into a fund. The reimbursement is done on a per capita basis. The administrative efforts in this case are reduced. Part of the money raised can go into the extension of public transport, then offering the more attractive choice for the larger part of society.
Switzerland is pioneer in these considerations.

Institutional barriers: The requirements for industrial self-contribution of up to 50% or even more, especially in the cases of extended photovoltaic and solar electricity generations as well as in the case of hydrogen technologies, should be reconsidered.
Furthermore, in the light of a consistent long-term policy reliable, appropriate and gradually growing federal support is required over long periods.
Of very high importance is the testing of key technologies under realistic conditions. This requires the build-up and operation of demonstration plants of growing size which by time shall lead to large scale systems ready for market introduction. As soon as possible the support of demonstration plants shall be succeeded by regular economic support measures.

According to the findings of the German advisory commission to the German parliament '*Technology Assessment - Conditions and Consequences of Build Up Strategies for a Solar Hydrogen Economy*'in 1990, the presently active institutions in the funding of renewable energies should be supported by:

- private, communal and cooperative energy service and contracting companies,
- permanent energy consulting and planning groups in public authorities,
- energy consultants in municipal and industrial enterprises and
- special departments for rational energy use and renewable energy application in municipal utilities and private industry;

which among others should generate:

- information material,

- carry out permanent surveys on activities in the fields of rational energy use and renewable energy application,
- set up guidelines for installation and operation of such applications,
- build up data bank services on such applications,
- consult and support municipalities, commerce, industry and private households with respect to technology, application for funds, financing, planning, conceptualization and establishment of integrated supply concepts (e.g. least cost planning),
- evaluation of projects for funding and related monitoring,
- initiation and performance of seminars,
- mobilization of technology transfer between research, production and application and
- working out of financing concepts together with banking institutions.

Regulatory barriers: In the case of international rules as set up e.g. by the IMO, application for modification or amendments will only be successful when brought up by at least two or more member countries. Whenever specific pilot or demonstration projects start into such technologies which are not yet included in existing national or international codes and regulations it is worthwile to start also into application work for amending missing regulations. Applications should always be filed by several interested partners which for international codes as e.g. IMO or ISO should come from different member countries. Pilot or demonstration projects therefore are very valuable and helpful for the advancement of technology also in this aspect by providing safer grounds for later realization (establishment of safety rules, construction codes, and operating instructions).

Legal barriers: In order to improve the situation of clean renewable energy concepts in Germany the existing law regulating the duties of utilities should be modified to such an extent that the environmental aspects of electricity generation are reflected appropriately and that more decentralized electricity and heat generation is encouraged (this is valid for many other countries as well). Environmental protection should be given at least the same priority as reliable, safe and economic energy production. Many critics even ask to put environmental considerations at highest priority, which at the long run certainly will be mandatory - on a worldwide scale. As a minimum requirement in a modification of the existing law should be considered the environmental compatibility, the careful treatment of resources, the equal handling of energy supply and energy services and the optimization of all factors for the provision of energy services (least cost planning).

Furthermore, the existing decrees on heat insulation and on energy conservation [EnEG] should be amended. Also the rule of utilization of residual matter in the federal law of prevention of immissions should be activated in order to facilitate the energetic uilization of biomass and of better waste heat recovery in industry. Adaptation of insurance codes in such a way that the real costs of certain technical systems (e.g. nuclear energy, transportation sector) are reflected more realistically, thus indirectly relieving renewable energies and clean energy and transport concepts.

Since in the opinion of some local authorities and community governments the implementation of environmental considerations into laws takes too long, in some regions or communities e.g. much higher remunerations are paid for renewable or clean produced electricity than only the ones for avoided costs as on the federal level. Many communities in Germany (about 100) are members of the so called climate coalition which supports the goal of the German government to reduce CO_2 emissions by 25-30% from 1987 levels until the year 2005. Some community owned utilities in Germany, Switzerland and Austria presently start to recompensate for the real generation costs of e.g. wind or PV electricity. These communities are also encouraging co-generation of heat and electricity and support energy conservation measures very actively. The increases in electricity rates to be paid by the consumer are only very small, since at the beginning the overall contribution of renewably or clean energy to the total amount consumed is still minor. Such arrangements encourage producers of renewable energy generation equipment or conservation technologies to increase their manufacturing capacities and thus to reduce their costs.

Lack of dissemination: To improve the situation for the consumer or citizen with respect to information, training and professional advice many different activities are indicated and recommended by the German advisory commission to the German parliament '*Technology Assessment - Conditions and Consequences of Build Up Strategies for a Solar Hydrogen Economy*' in 1990. Among these are:

- Information and continued education in schools, professional schools, academies and consumer advice centers
- Establishment and support of energy information and service centers together with utilities and community administrations
- Granting of subsidies and tax depreciation possibilities for energy consulting services
- Subsidies for instruction courses carried out by professional associations
- Encouragement of commitments by manufacturers to label their products with

information on energy consumption data

- Granting of certificates by industrial and consumer organizations
- Performance of various studies on local potentials for renewable energies and energy conservation, on integrability of renewable energies into conventional energy supply structures
- Detailed investigations on the consequences, risks, cost and conditions of the realization of nuclear energy systems, with special focus on a long term supply and disposal of nuclear fuel, on reprocessing of nuclear wastes and on the demolition of nuclear plants, in order to come to reliable lifecycle balance costs of nuclear energy generation

How to promote new R & D:

In general, the clearer and more reliable the boundary conditions are set up by governments in order to signal a structural change into the direction to renewable and cleaner energy technologies the sooner and the more profound industrial response will be. Many complaints from industry can be summarized as hinting on a defeciency in reliable and favourable boundary conditions encouraging more company R&D in the field of renewable energy and hydrogen technologies.

The better the industrial request is coordinated and jointly formulated (beyond any particular competitive resentment), the better it will be received by the funding institutions and the more probable a support for a concept will be.

Additional Comments

Strategic Considerations:

There are various strategic considerations which may influence our decision for the selection of type of our future energy system(s). Among these are the finiteness of fossil resources, the increased greenhouse effect and ozone depletion, the population growth and its local focal points, the local state of development, the present and aimed at general environmental, social, cultural or political conditions, as well as aspects of industrial competition.

For the introduction of renewable hydrogen priority could be given to such areas which globally contribute at high levels to the total humanmade CO_2 emissions, such as e.g. the road transport sector (10%) and steel fabrication (> 10%). Fast growing aviation is another sensitive area, not so much due to the total amount of greenhouse gas emissions but more due to the location where the emissions occur - in the very senistive layers of the higher troposphere and the tropopause.

With respect to the establishment of a solar electricity and hydrogen supply system the existing European interconnected supply infrastructure for electricity and gas should be evaluated. Especially should be examined if a similar agreement as the EURATOM-treaty could be established also for renewable energy sources. Besides the southern European countries of the EC the north African countries have high insolation values. Most of the north African countries have very clear ideas and partly also specific programs about decentralized utilization of solar energies. Due to lack of financing and professional expertise in these countries, the programs on solar energy are not advancing rapidly enough. The German advisory commission to the German Parliament '*Technology Assessment - Conditions and Consequences of Build Up Strategies for a Solar Hydrogen Economy*' of 1990 recommends that the EC enters into negotiations with the Union of Maghreb States in order to accelerate the utilization of solar energy at large scale in a coordinated manner and at an early time.

To open the option 'Solar Hydrogen' further the following steps of development are recommended:

- continue development of the key technologies of a solar hydrogen economy as named in the German advisory commission to the German parliament '*Technology Assessment - Conditions and Consequences of Build Up Strategies for a Solar Hydrogen Economy*' of 1990 and in the ad-hoc advisory group to the BMFT of 1988,
- consequent continuation of solar hydrogen demonstration projects of growing size,

- further development and application of advanced electrolyzers of larger capacities (several 10 MW),
- demonstration of hydrogen utilization as energy carrier (e.g. cogeneration, fuel cell plant, catalytic heater, buses, airplanes) with special focus on the reduction of NO_x,
- utilization of hydrogen as a decentralized means of storage for village and isolated energy supply systems (especially in developing countries), demonstrating the self-sufficient supply of energy with solar energy sources,
- detailed specification of the utilization of remote hydropower potentials via hydrogen which cannot be tapped with electricity directly and
- detailed studies on the large scale production of solar cells (waste management, recycling, energy conservation) and on detailed design of large solar generating capacities with main focus on local radiation balances, optimum siting, hydrological balance (sea water desalination, combination with irrigation), and infrastructural implementation (industrial development, oxygen utilization).

In this context it might be of interest what the above cited German advisory commission to the German Parliament has shown with respect to the feasibility of a concept for the replacement of a part or all of Germany's /at that time only western part of the country/ fossil energy system by renewable energies and hydrogen. For both investigated scenarios (with or without nuclear energy) it could be shown that renewable energies can provide between 7% and 13% of Germany's end-energy demand in the year 2005 at an average annual cost (investment + operating costs) of 10 billion DM (which in 2005 reach 17 billion). Hydrogen would not yet play any role in the year 2005. Is this approach consequently carried on until the year 2050 the resulting energy system will cover the end-energy demand with renewable energies and hydrogen at a 70% share. Between 2005 and 2050 the average annual costs are in the order of 70 billion DM (190 billion in 2050). For this 70% end-energy coverage in the year 2050, German society then would have to spend about 6.5% of the gross national product forecast for this time - a share not larger than today.

Already today half of the world population lives in urban agglomerations, 65% in industrialized countries. This share will also be reached for developing countries in a not too distant future. Concentrated energy carriers, such as electricity and gas, will be a prerequisite for an efficient energy supply, also of energy produced from renewable sources.
In case there will be no major breakthrough in technically and economically feasible superconductive electricity storage and in case the growing constraints on the use of fossil energies are understood and accepted, hydrogen can become growingly important as an energy storage media for

renewable energies fluctuating in supply (solar, wind) as well as an energy carrier (i.e. as a *facilitating* technology) providing clean energy to the places of demand.

In 1991, Japan imported more than 50 billion m³ of natural gas in liquid form (LNG) thus absorbing approximately 70% of the world LNG trade. Since these imports cover almost 40% of Japans primary energy needs they are of strategic importance. As will be an option for a future replacement of these imports. Maybe a reason for Japans interest in hydrogen and for the We-Net program initiated.

Internalization of External Costs:

In Europe and especially in Germany a broad discussion started up on external effects related to energy utilization and to the transport sector already some years ago.
Mainly our catastrophic situation in road transportation has increased the common consciousness about the negative side effects caused by heavy duty cargo transport with trucks and by 'mass' transport via passenger cars (statistically occupied by 1.3 persons). Although the car density per capita especially in united Germany is still lower than that in the USA the density per existing km of roads or per area is some 2½ times higher than in the USA. This, in conjunction with historic urban centers and different settlement patterns has led to almost continous congestion of roads in some areas. The improvement of related infrastructure, such as number and design of roads, electronic road management, parking space, etc. has already proven or is presently proving not to be the long-term solution since it attracts more traffic and thus at the long-term will not smooth the situation significantly. On the other hand, public transportation, though not yet being ideally tailored for all users' needs, but much further developed than in e.g. the USA, cronically suffers from deficits.

Presently it seems that this situation can be solved only by approaches which in many eyes seem radical ones: closing the civic centers for individual traffic (passenger cars) and providing clean public transport systems (subways, street cars, clean buses); better interconnection of long distance transport systems (train, airplane) with local public transport or individual transport (cars, taxi, road&rail, etc.). These systems will more easily develop if the overall costs for inefficient individual transport systems are raised significantly. Easiest way to do so from the administrative point of view as well as the most efficient way from the ecological point of view is raising the fuel/ energy taxes significantly.

Such measures are justified due to various side effects caused by e.g. cars or trucks, which have the highest specific emissions (NO_x, CO_2, SO_2, C_xH_y) and much higher accident rates and consequences per passenger/ton kilometer (car compared with bus or train, truck compared with train), and which are mainly borne by society in the form of fighting the consequences of acid rain, greenhouse warming, ozone depletion and in general in the form of higher insurance rates (reinsurance companies as e.g. Münchner Rück are reconsidering the risks related to greenhouse warming effcts and if they can be insured in the future).

All these considerations also refer to energy generation from fossil sources as well.

The money recovered by the government can be used to improve/ support improvement of clean transport and energy infrastructure and to lower taxes and duties on human labor (income tax) and private investment.

At the long run, internalization of external effects will only work if a sufficient political majority and a broad acceptability by the population can be achieved. This will also mean that a broad consensus about a future concept for energy generation and utilization (i.e. the energy system) will have to be achieved in society.

A partial remedy for the negative effects caused by our present energy and transportation system can be a fundamental change in attitude which in future will give priority to the type of possible services to be provided in order to cover certain needs than on the particular product which might fulfill these services.

Long-Term Planning and Learning Curves:

Technical history demonstrates how long in average technical products, concepts or systems need to achieve a significant market penetration. One very simple example from automotive industry is the anti blocking system (ABS) in cars, which from its first steps into development to its present wider market introduction (although still below 50% penetration) needed some 30 years. Each newly installed production process when put into operation needs a certain time to function without defects and on the other hand the given capacity of the production line never will permit extension of production quantities above a certain threshold due to learning curve behaviour.

Other examples on a higher aggregate level stem from the energy economy showing how long the replacement of one energy carrier by another one took place. Thus within the last 2 centuries wood was replaced by coal and coal by oil as the major energy carrier. The replacement of oil presently seems not yet decided since all options seem to have their advantages and setbacks and especially in the rich countries the awareness about the setbacks seems to grow. But these setbacks on one side and the nature of learning curves on the other side indicate the necessity to come to decisions on the character of our future energy system soon.

Having understood these mechanisms properly, we can think about how our future energy system should look most likely and of which components it may consist. Since future over a longer time span never can be planned completely, at least the options selected today should ensure systems which will not impose incalculable burdens on future generations, especially when possible setbacks are imaginable or even foreseeable at present stage and other options exists and suit the needs equal or similar. Only looking on economic aspects as practised nowadays seems to be a very weak approach since many of the real costs presently incurred are not reflected by our present way of decision making and thus automatically lead to misallocation of funds.

If we come to the conclusion that renewable energies and energy carriers are preferable for the future, we have to decide when we want to employ which magnitudes of these technologies. Due to the learning curve effect we approximatively can determine when we have to start large efforts in order to introduce these technologies into the market or if it is already too late to achieve a given goal, thus leading to a possible revision or modification of this goal or to a possible switch to other concepts.

Conclusions:

In the wake of rapidly growing world population and changing climate patterns fast and preferably harmonized activities are required worldwide for the improvement of energy efficiency, the optimization of appropriate supply (infra)structures and the provision of clean and environmentally compatible energy sources. Although it still may take some time to come to international conventions, national measures to improve the situation should not be postponed with the common argument that an international harmonization is still missing and that due to economic reasons one cannot do the first step. Some countries which invested in environmental protection technologies first, also were the biggest players in these markets later on (e.g. Japan and Germany). Maybe this can serve as an example for an initiative on large-scale use of renewable energy and hydrogen technologies.

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List of Abbreviations Used:

BMFT	Bundesministerium für Forschung und Technologie (German Ministry for Research and Technology)
CEC	Commission of European Communities
DM	Deutsche Mark
EC	European Community
ECU	European Currency Unit (MECU = million ECU)
EQHHPP	Euro-Québec Hydro-Hydrogen Pilot Project
IMO	International Maritime Organization
ISO	International Organization for Standardization
kW	Kilowatt
kWh	Kilowatthour
MW	Megawatt
RD&D	Research, Development and Demonstration

Exchange Rates:

Rates of exchange with status of March 1993:	1 ECU = 1.966 DM = 1.16 US$
	100 ¥ = 1.40 DM = 0.82 US$

SACRAMENTO MUNICIPAL UTILITY DISTRICT TESTIMONY BEFORE THE UNITED STATES SENATE COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS SUBCOMMITTEE ON TOXIC SUBSTANCES AND RESEARCH AND DEVELOPMENT

Renewable hydrogen will provide power for transportation and electrical generation with no pollution or toxic wastes. The Sacramento Municipal Utility District (SMUD) plans to demonstrate applications for renewable hydrogen as soon as possible. Our 1993 budget includes almost one million dollars of funding for renewable hydrogen projects. We hope to leverage this funding into one or more integrated renewable hydrogen projects in the next few years.

SMUD is a publicly owned electric utility located in California's central valley. Our valley location, and our population density, have caused significant air quality deterioration over the recent decades of growth. Since Sacramento does not have a large industrial sector, solutions to our air quality problems must be found primarily in the transportation sector. There are no emission controls that can be imposed upon the industries of Sacramento to give even short term improvements while better transportation technologies are developed. We must strive to implement improvements in the transportation sector as soon as possible to avoid continued deterioration and continued deleterious health effects. In many ways we are an example of what is to come for the nation as a whole. We have reached the point where action is required quickly. Every population center in the United States will certainly reach the point where significant changes must be made in transportation systems to avoid unacceptable air quality conditions.

SMUD will strive to electrify the transportation sector in Sacramento County within ten years. Hydrogen can help us achieve our goal. This is the kind of significant change that can bring about the improvements in air quality that we all need. In order to accomplish this, we will incorporate several approaches. We are building electric trolleys with overhead power. Sacramento already has an electric light rail system, that we will help to expand. Our fleet now includes battery electric vehicles, both conversions and purpose built electric cars. Our electric vehicle charging systems include photovoltaic energy to avoid reliance on fossil fuels. Our development efforts include ultra-light vehicles, as well as high power-density flywheels. But the most advanced concepts, holding the promise of truly meeting all our transportation needs in the longer term, centers on fuel cell vehicles.

SOLAR HYDROGEN FUEL CELL BUS

Fuel cell vehicles can extend the range and improve the performance of electric vehicles. Solar hydrogen fuel cell vehicles have the advantage of totally clean renewable energy. No fossil fuels are used. The only byproduct is pure water. The SMUD solar hydrogen fuel cell bus will truly be a **zero emission vehicle.** Additional advantages of fuel cell vehicles will also be demonstrated. The fuel cell power source can serve as transportable auxiliary power for remote or emergency use. The fuel cell power source can also provide heating and cooling for the bus. This type of integrated project will serve as an example for additional fleet applications nationwide.

SOLAR HYDROGEN

Solar hydrogen makes this all possible. Hydrogen is the energy carrier that allows the high efficiency fuel cell to provide electrical energy at the point of need. Hydrogen's ability to serve as a totally clean energy carrier is key to the process. Hydrogen must be used to truly achieve the clean air promise of several advanced and renewable technologies. This is particularly true of solar energy technologies, that can only convert the sun's energy during daytime hours. Hydrogen can be used to store and transport solar derived energy for later use. Converting hydrogen to heat and/or electricity can then be accomplished with no polluting emissions.

The SMUD solar hydrogen fuel cell bus program will utilize photovoltaic solar power cells to electrolytically separate water into hydrogen and oxygen. The hydrogen will be stored for later use on the bus. The bus storage system will use pressurized storage, or other appropriate storage system developed for this application.

Photovoltaic cells are not the only way to produce solar hydrogen. Biomass resources, using plants to capture the energy of the sun, can also be used to produce solar hydrogen. Technology originally developed for coal gasification can be used for this purpose. The technology can be modified and applied to biomass, producing hydrogen rich gaseous fuel. This technology should be applied now in integrated fuel cell demonstration projects to showcase its advantages. Independent of fossil fuels, it has the advantage of fuel security. Using fuel cells to convert the hydrogen gas to electricity and heat, it produces no pollution. Since it uses plants that absorb carbon dioxide when they grow, it produces no net carbon and will not contribute to greenhouse gases.

Renewable hydrogen can also be produced using existing off-peak electrical generation such as hydroelectric resources or wind power. These energy sources produce no pollution, but their output varies based on wind or water flows. Hydrogen provides the means to store the output for use when it is needed, even at remote locations or in vehicle applications. Renewable hydrogen will be part of our energy future. It is important that we take the opportunity to demonstrate its applications now. In this way we will be able to gain experience with its use, encourage cost reductions, and foster reliability.

HYDROGEN FUEL CELLS

Fuel cells use hydrogen to produce electricity very efficiently. Fuel cell electrical efficiencies of up to 60% are expected. Fuel cell electric vehicle drive train efficiencies are more than double the efficiency of current fossil fueled vehicles. This higher efficiency compensates for the current price advantages of fossil combustion engines, and totally eliminates their pollution. Stationary fuel cell power plants will also benefit from this efficiency. As a simple example, the current biomass power plants have efficiencies of about 25%. Fuel cell power plants will be more than twice as efficient. This means that biomass fuel cell power plants can be more than twice as fuel efficient for their owners.

Integrated fuel cell projects will allow costs to be verified, while practical application of fuel cell technologies will encourage further cost improvements. Practical applications will also verify reliability, while familiarizing utility personnel with their use. Both stationary power and vehicle systems can be demonstrated now. The attached table can be used as a guide to hydrogen fuel cell projects that could lead to widespread benefits in the next ten years.

APPROACH	PROJECT TYPE	EFFORTS	FEDERAL BUDGET	EFFECTS
Federally coordinated solar hydrogen fuel cell bus demo.	Fleet use of solar hydrogen fuel cell busses in selected markets.	8 regional markets to be selected. 6-10 busses per fleet. Phased in over three years.	$30M per year.	$180M to private sector industrial manufacturing. More than 1200 jobs added to the private sector.
Federally coordinated solar hydrogen locomotive demonstration.	Operating solar hydrogen fuel cell locomotives in several applications.	6 locomotives per year for four years. 10 locomotives per year thereafter.	$60M per year.	Over 1200 private sector jobs added permanently to the locomotive industry base.
Integrated renewable hydrogen fuel cell vehicle fleet demonstrations.	Demonstration of stand-alone renewable hydrogen fuel cell vehicle fleets.	Four fleets in selected markets to start. One fuel production, storage and refueling system per fleet. 8-10 Vehicles per fleet. Initial fleets phased in over three years. Additional fleets at two per year.	$20M per year.	$200M over 5 years to private sector transportation and manufacturing industries. Over 800 private sector jobs.
Coordinate efforts to demonstrate biomass fuelled high efficiency power plants.	DOE coordination of integrated biomass gasification fuel cell projects. Cofunding by utilities and manufacturers.	2 demonstrations in 1994, 2 scale-up projects in 1995, 5 additional demonstrations each year for three years thereafter.	$20M federally funded per project. Annual federal budget of $40M.	$800M to domestic fuel cell manufacturers, equipment suppliers and construction personnel. Up to 1600 jobs.
TOTAL			$150M ANNUAL FEDERAL	OVER 4800 PRIVATE SECTOR JOBS

It is important to emphasize the integrated nature of these fuel cell projects. Without the hydrogen production systems, the fuel cell is not a pollution free renewable energy source. The high efficiency of fuel cells tends to amplify the benefits of hydrogen. It is important to include both renewable hydrogen production and fuel cell utilization to maximize the value of these integrated demonstration projects.

The ability to focus on hardware demonstration projects allows jobs to be added to the private sector. This results in thousands of jobs due to use of these renewable hydrogen technologies. The renewable hydrogen and fuel cell technologies are thereby integrated into the U.S. manufacturing sector. The hardware demonstration projects also continue to provide energy into the future, helping to pave the way for improved systems to follow. The essential ingredient of economies of manufacture is also provided by encouraging manufacturers with sustained markets for their goods and services. This allows manufacturers to plan for a sustained development period, leading to widespread utilization.

COMPETITION IN THE INTERNATIONAL MARKETPLACE

Hydrogen technologies have been widely applied by aerospace endeavors in the United States. U.S. industry has extensive experience with hydrogen production and use. This experience can be easily converted from predominantly defense and space applications to transportation and power generation applications. Facilities, techniques, standards and procedures exist for both pressurized and liquid hydrogen service. Electrolytic separation equipment is available from United States firms to separate water into hydrogen and oxygen. U.S. fuel cell manufacturers have successfully supplied fuel cells to the NASA space program, as well as to utility demonstrations here and in Japan.

But foreign firms and governments are doing more. The Japanese government, in cooperation with their utilities, is actively pursuing fuel cell power plants with subsidized projects. The Canadian government is providing funds to Canadian firms to subsidize fuel cells and solar hydrogen production in Canada and the United States. Canadian and German firms are actively pursuing fuel cell market share, with the first fuel cell powered bus recently unveiled in Vancouver. German and Japanese auto manufacturers have active hydrogen vehicle programs, aimed at the ultra low emission vehicle market that California has helped to define. It is time to recover this essential technology to benefit the people of the United States.

In moving from a military intensive economy to an infrastructure based economy, the renewable hydrogen fuel cell technologies are uniquely positioned. Our technical know how can regain lost market share. Our manufacturing industries have the tooling and materials. The need for this equipment is vital and current. The only thing missing is an assured market of early adopters, with funding to bring these improvements to our infrastructure.

THE FEDERAL ROLE

By funding these improvements to our infrastructure, the Federal Government can add jobs to the manufacturing sector, while improving air quality and increasing energy security. This is a vital service of government. By bringing these new renewable hydrogen technologies into the service of the people of the United States, we all benefit. In addition to the air quality benefits, we reap the benefits of improved standards of living, and improved market share in a prime export technology. The renewable hydrogen fuel cell can serve as the transistor of the 21st century. If we have the foresight to apply it now, we can reap the benefits for our children.

Testimony of

Dr. G. Neal Richter

Texaco Honorary Research Fellow

Alternate Energy and Resources Department

Texaco Inc.

before the

United States Senate

Committee on Environmental and Public Works

Subcommittee on Toxic Substances and

Research and Development

March 22, 1993

Good morning Chairman Reid. It is a pleasure to have this opportunity to testify before you and the other members of the Subcommittee on Toxic Substances and Research and Development. My name is Neal Richter. I am an Honorary Research Fellow with Texaco's Alternate Energy research laboratory in Montebello, California. We greatly appreciate the opportunity to contribute to this discussion on the current state of environmental technologies related to the development of renewable energy sources, specifically in the hydrogen energy sector. I also want to use this opportunity to share with the Subcommittee some of the broader applications of gasification technology, specifically in regards to the beneficial re-use of industrial and consumer wastes.

It should be noted that Texaco Inc. is the only major oil and gas company that has maintained an alternate energy program throughout the 1970s, 1980s and now into the 1990s. We believe Texaco is uniquely qualified to speak to the production of high purity hydrogen because of the worldwide commercial use of Texaco's Gasification Process (TGP) technology for the production of hydrogen, among other products, for over 40 years. This Texaco Gasification Process can utilize gaseous feedstocks, such as, natural gas and other low valued gaseous waste streams. Likewise, a wide range of liquid hydrocarbon feedstocks, such as, LPG, naphtha, heavy fuel oil and more recently solid feedstocks, such as, coal or petroleum coke can be utilized to produce various products, including hydrogen. There are 47 commercial units currently operating or under construction worldwide which have licensed the Texaco

Gasification Process, representing over 2.2 billion standard cubic feet per day of synthesis gas (hydrogen + carbon monoxide) generation capacity.

Texaco's research facility in Montebello, California, is devoted to process research in support of Texaco's Gasification Technology. This facility contains pilot plant units that verify feedstock acceptability and confirm process performance parameters. This facility allows us to do extensive research on new and more cost effective ways to produce hydrogen. Based on years of testing and given the ability of the Texaco's Gasification Process to deal with a variety of feedstocks, including its ability to destroy organic and inorganic compounds, it is an ideal means of converting waste material to desirable and useable products. Therefore, although today's meeting mainly addresses the production and utilization of hydrogen, the ability of Texaco's gasification technology to handle waste material has far reaching applications in meeting the environmental needs of the U.S. economy.

Texaco's Gasification Process has been a technology of choice for hydrogen generation for more than 40 years. We have a well developed, continuous expanding, fully commercial and successful gasification process for the manufacturing of hydrogen.

We see the U.S. demand for hydrogen increasing dramatically over the next decade, while the existing hydrogen supply is expected to drop. The Clean Air Act Amendments of 1990 require refiners to lower aromatics in gasoline, resulting in less hydrogen recovered by refiners from catalytic reforming units. Meanwhile, requirements to reduce sulfur in diesel fuel will require additional hydrogen capacity. According to Texaco's estimates, new hydrogen demand by U.S. refiners could exceed four billion standard cubic feet per day over the next ten years. Texaco has recently enhanced its gasification process to produce high purity hydrogen to meet this demand in a more economical manner by incorporating the latest industrial purification technology. Texaco offers this technology for license through a U.S. patented process called HyTEX™. The proprietary HyTEX Process is designed to produce high pressure, high purity hydrogen from gaseous refining waste streams in an environmentally superior and economically competitive way.

The HyTEX process is environmentally superior to alternative hydrogen generation processes, such as, steam methane reforming, in two specific areas. First, the HyTEX process has virtually no NO_x emissions because the process does not contain a large reforming furnace with extensive stack emissions. The HyTEX process is basically a closed system with minor air emissions if a packaged boiler is utilized. Second, because of the feedstock flexibility of the Texaco gasifier, assorted gaseous, liquid and solid waste material can be used in the HyTEX process. In this way waste streams are converted into a valuable product; in this case hydrogen. The steam methane reforming process normally utilizes only nonrenewable clean feedstocks, such as, natural gas.

Furthermore, to meet this need Texaco Inc. formed a joint venture company with a major industrial gases company in 1992 to supply hydrogen on a long-term basis to industrial users. This is a major endorsement of our technology and we have received significant interest in the marketplace for hydrogen. Companies have a combined interest in high purity hydrogen and in reducing overall plant emissions.

The Texaco Gasification Process, coupled with the combined cycle power block, has been demonstrated as an efficient means of using coal to generate electricity with superior environmental performance. In fact, the technology produces SO_2 and NO_x emissions which are approximately only 1/10th of the EPA's New Source Performance Standards.

Through further study and demonstration we have learned that due to the extremely high temperatures of the process, virtually any organic waste is destroyed. This in combination with the technology's ability to encapsulate any metals in a non-leachable form, provides us with a method of waste destruction which is superior to incineration. The possibility of using municipal and other waste streams to supplement the feedstock for the gasifier provides an environmentally beneficial aspect.

Our technology's ability to use waste streams to partially feed the gasifier could result in a substantial reduction of waste going into municipal landfills. A shift toward gasifying municipal sludge, used oils, tires and other wastes could dramatically reduce solid waste handling requirements. Using this integrated approach to coordinating applications should maximize the benefits derived from each environmental technology expenditure.

The application of Texaco's Gasification Process has been closely followed by various governmental agencies and national laboratories. We are presently discussing research projects with some of these agencies, which address many of the matters being discussed today on hydrogen production, storage and distribution. These agencies and researchers have initiated these discussions due to Texaco's more than 40 years of experience in hydrogen generation and the environmental economic benefits from gasifying sewage sludge, tires, used oils and various forms of biomass.

It should be noted that under a grant from the California Department of Health Services (DOHS) Texaco successfully demonstrated the gasification of low BTU liquid hazardous waste to produce synthesis gas and non hazardous effluents. Furthermore, Texaco is presently working with the Environmental Protection Agency in their "Superfund Innovative Technology Evaluation" - SITE program, to examine the potential of gasifying hazardous wastes, producing non-hazardous material which could be utilized to produce hydrogen and power. Recent testing at Montebello has demonstrated that Texaco's gasification technology can convert materials like used tires and lubricating oils, municipal sewage sludge and plastics into clean synthesis gas. Also work is underway at our Montebello Research Lab to integrate Texaco's Gasification Process with Fuel Cell technology. Future application for hydrogen storage may be an added benefit from this research.

In pursuing these objectives we have discovered, ironically, that the barriers which tend to hamper development of new environmental technologies seems to be the manner in which the regulations and procedures are managed. Enormous delays in obtaining permits or variances to perform tests are experienced. Often there is something close to a "Catch 22", with it being impossible to deploy a technology to improve the environment on a broad scale, until the process has been successfully tested on a large scale in the laboratory. However, a large enough test to be meaningful might require two or more years to permit.

It might be possible to obviate these difficulties by encouraging the EPA and state governments to recognize the importance of expediting review, when prospective processes may provide benefit programs under the control of other jurisdictions. For instance, if a process might result in a significant solid or hazardous waste reduction, then those responsible for air permitting should consider that aspect and expedite permitting. Variances for environmental research should be expanded and expedited for the testing of new technologies and applications, so long as adequate precautions are maintained.

In addition to creating a process which is technical feasible, we must also demonstrate that the specific projects are economically viable and result in sufficient benefits. In many cases, in order to benefit from the large economies of scale the use of gasification to generate hydrogen must be done in combination with a power contract. However, most Public Utility Commissions (PUC's) have a discrete agenda that does not encourage a broader societal view. The integration of these environmental and economical advantages are becoming critical to the many applications for these advanced technologies.

Thank you, again for this opportunity to address the Subcommittee. It has been an honor for me to appear before you today. I would be pleased to address any questions you may have.

Hydro.WP

MCDONNELL DOUGLAS

McDonnell Douglas Aerospace - Huntsville

United States Senate
Committee on Environment and Public Works
Subcommittee on Research and Development
Washington, D. C. 20510-6175

Hearing on the Environmental Impacts of Accelerated Research and Development in the Renewable Energy Sector, March 22, 1993

Statement by Dr. W. P. Olson, Vice President-General Manager, McDonnell Douglas Aerospace-Huntsville Division

Gentlemen;

McDonnell Douglas is pleased to provide testimony regarding our experience with renewable energy resource engineering, research, and development. We have prepared an overview of our oral testimony, outlining our position on these matters, together with a more detailed written response. Our detailed response is organized first, as a description of the McDonnell Douglas Corporation; second, as a summary of our experience in renewable energy, especially solar energy and related technologies; third, as answers to the questions raised in the letter of invitation from this subcommttee, dated February 16, 1993; and fourth, as a suggested approach for consideration of issues related to accelerated research and development of promising renewable energy resources.

Overview

The McDonnell Douglas Corporation has had a long term interest in the application of space technologies to solve problems here on earth. We are also concerned about the declining national investment in aerospace defense and the growing ranks of unemployment among our highly skilled workers. It is our hope that the interests of this committee will result in opportunities for jobs in the depressed aerospace industry, as well as foster clean, efficient, and cost effective forms of renewable energy.

We have observed a growing interest in the use of hydrogen fuel as a potential replacement for certain petroleum fuel applications and in the use of solar energy to generate the electrical power needed to produce large quantities of hydrogen for use as a fuel. We are also seeing renewed interest in solar energy as a supplement for our nation's existing network of electrical power generation. Solar energy may also be a means to reduce or eliminate unwanted environmental effects and to reduce our nation's dependence on foreign supplies of petroleum fuels.

McDonnell Douglas invested heavily in solar power technology in the 1970s and early 1980s. We designed and built two of the most successful types of solar energy

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conversion systems produced to date: a system we call the Dish Stirling and a central receiver solar thermal power system. Both of these employ reflected sunlight to heat a working fluid that drives an electrical generator.

We terminated our work on these systems about 8 years ago and wrote off heavy losses. We were prompted to enter this field of technology development because of government interest in alternative power sources and the growing cost of petroleum fuels at that time. Once fuel prices dropped, the interest in large scale solar power also dropped in both the public and private sector and we were forced to abandon this technology at that time.

We saw a brief revitalization of interest in solar energy in one of our primary business areas, space technology, in the mid to late 1980s when the initial concepts for Space Station Freedom were being formed. At that time, the use of solar-dynamic power generation, which is the generic form of our Dish Stirling system, was selected for use on Space Station Freedom. This form of solar power, which is efficient, compact, and non-polluting, was selected for the growth phase of Space Station Freedom when higher power levels would be needed. In subsequent years funding reductions forced the down-sizing of the station and deletion of this and other advanced technology items.

We have retained our interest in this technology, however, both for space as well as for terrestrial use. But, conditions in our industry today do not permit investment in new technology unless there is a strong commitment on the part of our government customers, as evidenced by adequate, stable funding.

It is also interesting to note that the space industry is the largest user of hydrogen as a fuel for transportation. Liquid hydrogen and liquid oxygen provide one of the most efficient rocket propellants known. We have been successfully and safely using these propellants for over three decades and have developed sophisticated techniques for the handling, storage, and transfer of these materials in both liquid and gaseous form using applications of space technology engineering, manufacturing, and processing methods. We already have in place a successful ground infrastructure that services the industry with liquid hydrogen and oxygen as well as more exotic fuels. When used in space, hydrogen fuel combining with oxygen produces only water, the same compound from which the materials are obtained through electrolysis. Its use in ground applications produces the same result, which is non-polluting and based on inexhaustible sources: sun energy and water.

We see exciting possibilities in the application of solar power and hydrogen fuel, but we are not excited about the prospect of investing again on the basis of hope and promise. We believe that the U.S. could become a world leader in the application of these technologies, but this will require serious commitment and substantial investment. And, the U.S. is not the only nation interested in the benefit of these technologies. We anticipate that these hearings will provide surprising evidence of interest and progress in other leading, and competitive, industrial nations, such as Germany and Japan.

We recommend that an agency of the U.S. Government take the lead to revitalize research and development in these technologies at a rapid pace with one objective being the demonstration of the Dish Stirling concept as a supplemental source of low cost, non-polluting electrical power within the next few years. In parallel, this agency should support the development and demonstration of hydrogen as a transportation fuel together with a ground infrastructure that would make distribution of this fuel practical at the consumer level. Finally, this agency should implement a pilot project that would allow demonstration of solar power generation, water electrolysis, and hydrogen storage systems as well as distribution systems and operating vehicles. While all of this may sound complicated on the surface, these types of technologies are routinely applied in the design, construction, and operation of complex space systems. Many people have difficulty understanding the benefits of investing in space technology. Perhaps this type of program would demonstrate the value of leadership in the high technology domain of space and help to restore once again our nation's desire to become a leader in space. In the meantime, an accelerated development program in renewable energy would offer practical opportunities for high technology and manufacturing jobs for the thousands of unemployed defense and aerospace workers in our nation.

Detailed Response and Testimony on Renewable Energy Resources

Corporate Background

McDonnell Douglas Corporation is the nation's largest defense contractor, the world's largest builder of military aircraft, the third largest commercial aircraft maker in the world and the third largest NASA contractor. As such, the company is engaged in development and production of combat aircraft as well as commercial airliners, helicopters, space systems and missiles. In addition, the company produces electronic systems and is involved in finance and leasing.

Together with these major military, civil, and commercial systems, products, and services, the corporation maintains an extensive advanced technology capability and is one of the largest Department of Defense research and development contractors. Our key technologies include flight systems, materials and structures, electronics, computers and software, integrated design and manufacturing, control systems, artificial intelligence, propulsion and power, thermal systems, life sciences and life support, and systems engineering and integration. Our space technology business over more than 30 years has enabled us to develop a broad expertise in cryogenic systems, especially liquid hydrogen and liquid oxygen; this background is pertinent to the deliberations of this subcommittee in regards to the potential viability of a Hydrogen Economy.

In parallel with the corporation's primary products, McDonnell Douglas also conducts special projects to assess advanced technologies. For example, during the early 1970s to early 1980s, the company was engaged in research and development projects related to energy systems, including wind generation, advanced coal technologies, sea transport of liquified natural gas, and solar energy. The latter project is especially relevant to the deliberations of this subcommittee.

Solar Energy

McDonnell Douglas initiated studies of solar thermal electric power generation in 1972, starting with system and cost analyses and system designs, together with early subsystem development projects for a variety of solar concentrators. Coupled with joint efforts with our major subcontractors, we developed an overall system design selected by the Energy Research and Development Agency, later the Department of Energy, for implementation as a 10 Megawatt Electric Solar Thermal Central Receiver Pilot Plant, located near Daggett, California. As the system integrator for this plant, known as Solar One, we were responsible for all aspects of system design and for major coordination activities required to bring this plant online and operate it for over two years. The Solar One team included McDonnell Douglas, Martin Marietta, the Rocketdyne Division of Rockwell International, Steams Roger, the Los Angeles Department of Water and Power, the Southern California Edison Company and the Sandia National Laboratories. This team met or exceeded all of the design performance requirements associated with this plant, including operational efficiency and availability.

In the early 1980s, McDonnell Douglas initiated a totally company funded multi-million dollar development effort to design, fabricate, and test a 25 kWe Dish Stirling solar thermal electric power system. This program was conducted with United Stirling AB of Sweden, which had developed a solar receiver and Stirling engine. This system was tested over the course of several years at various utility sites as well as at McDonnell Douglas; it had a net efficiency of approximately 30 percent, the highest of any solar electric system in the world to date. These systems have demonstrated the potential for long life, typically of the order of 30 years; several of them have been operational for nearly 9 years with virtually no degradation in performance. Cost analyses at that time indicated that in production, the Dish Stirling system could be cost competitive with peaking and intermediate power systems, such as gas turbines, in use by the utilities in the desert Southwest; more recent studies indicate that refined versions of the Dish Stirling system may now also be cost competitive with baseload power systems, such as coal and nuclear. However, during the mid-1980s, it became necessary for the company to divest of its solar Dish Stirling effort, because the drop in oil prices, combined with a decrease in projected electricity demand, made the near-term market viability of solar energy highly questionable. At that time we also were forced to write off substantial losses.

McDonnell Douglas divested and sold rights for the Dish Stirling system to Southern California Edison in 1984, but it still retains a cadre of key personnel and the analytical, design, technology development, and systems integration capabilities required to conduct similar programs. We have the capability to conduct all of the major program activities related to research and development of solar thermal electric power systems, especially Dish Stirling and central receiver solar thermal power systems.

Answers to Questions in Invitational Letter

1. What areas of environmental technologies are being developed in your area of expertise?

McDonnell Douglas Aerospace has been engaged in the following technologies related to environmental and energy systems: solar thermal electric energy systems, especially the Dish Stirling system and the central receiver system; advanced optical alignment and evaluation systems used for solar energy development and operation; advanced control systems for improved solar tracking; solar detoxification systems for hazardous substances and waste treatment; composite tanks for cryogenic storage; use of robotics in remote applications, such as space assembly, fabrication, and environmental cleanup; system simulation/expert systems for analysis of complex problems; and use of neutron irradiation and detection of gamma rays for species identification of waste product constituents. The corporation is heavily engaged in space systems, such as Spacelab, Spacehab, and Space Station Freedom which are required for earth observation and research in materials and life sciences. We are also involved in the development of advanced communication and data management systems related to space systems and are the foremost developer of laser communications systems; these technologies are relevant to satellite earth observation and space research. Furthermore, we provide the nation's most reliable launch vehicle, Delta II, used to place satellites in orbit for communication, navigation, and earth observation of natural resources, weather, etc. We have conducted decades of development efforts in the areas of cryogenic propellant systems, especially liquid hydrogen and liquid oxygen, for use with space systems. These clean burning rocket propulsion technologies are particularly relevant to Hydrogen Economy considerations. We are also engaged in development of cleaner, quieter, more fuel efficient aircraft. We conduct extensive research efforts in the development of new materials. All of these technologies are either directly or indirectly related to environmental and energy systems.

Are they being developed in a timely manner and in conjunction with efforts in other areas of business and in coordination with appropriate federal programs?

In general, we have conducted our development efforts consistent with business opportunities and in coordination with appropriate federal programs. However, the growing concerns over energy dependence, resource depletion, and environmental and health issues associated with fossil fuels brings to the forefront the possible advantages of advanced solar energy systems and use of hydrogen. As federal programs are instituted to address these issues, and as the market opportunities develop, McDonnell Douglas can re-evaluate its technology activities and the application of its capabilities and infrastructure to the support of national efforts in this area.

2. What are some of the environmental benefits which would accrue from these technologies and how can these benefits be integrated in such a way that both the US economy and the international economy might be more competitive?

The Dish Stirling system and advanced versions of the Central Receiver Solar Thermal Power system both offer environmentally clean sources of electrical power. The potential of using hydrogen or natural gas as the power source for a hybrid Stirling solar-combustion system has been briefly examined and may hold promise; if this hybrid Stirling system is cost effective, then clean baseload power can be provided.

Aerospace technology, systems, and infrastructure associated with cryogenic propellants are directly applicable to the commercial use of hydrogen as a clean burning fuel. McDonnell Douglas is conducting research and development of advanced light weight, high strength composite tanks and structures. This technology would be applicable to hydrogen storage and transportation systems.

Solar Detoxification/Decontamination systems offer the potential for more thorough and cost effective treatment of certain hazardous chemicals through the combination of high temperature and photocatalytic conversion.

Identification of hazardous chemical constituents by advanced methods would reduce the costs of clean up by tailoring the optimum clean up techniques to the situation.

Use of robotics and system simulations for environmental clean up will increase cost efficiency, reduce manual labor, reduce health hazards to workers, and allow toxic materials, such as nuclear wastes, to be handled more safely.

3. What are the current barriers to developing the technologies in your area of expertise, e.g. legal, regulatory, institutional, lack of funding, incentives,etc.

The major barriers for development of these technologies, particularly the solar Dish Stirling and Central Receiver systems are funding limitations and lack of a well defined market. The utility market for solar and use of hydrogen is dependent on the cost competitiveness of these technologies. Systems analyses and pilot plants are needed to both produce the hardware, such as solar concentrators and engines, and to operate these solar thermal electric systems on a scale of sufficient magnitude to clearly demonstrate the total life cycle costs. Only when these sysems have been demonstrated to be cost effective will it be prudent to invest in them. A long term commitment at the federal level is needed to accelerate the development of these systems.

4. What steps could be taken to reduce or remove these barriers and promote new R&D of commercially available environmental technologies?

In the solar thermal electric energy area there are four major steps needed now: The first step is to conduct cost studies and market analyses to determine the overall cost effectiveness of the various solar energy concepts. Our analyses show that the Dish Stirling and advanced Central Receiver offer the potential for cost effective production of electricity, but commitment of government resources in these areas would first depend on the results of cost and market studies.

Second, the level of research needed for the solar thermal electric systems, especially the Dish Stirling system, is not high. What is required is a development effort to refine the design of the concentrator and engine to facilitate low cost, high rate manufacture of these subsystems.

Third, pilot plants should be developed to produce these systems at high rates and low cost. Because these systems are capital intensive and start up risks are high, government assistance is needed to reach the production levels required to be cost competitive with fossil and nuclear plants. Near full scale plants should then be operated in the field to prove the overall cost competiveness of these systems. This type of planned development will rapidly result in the most cost effective system for utility use, and assure the utilities that these systems are credible for their markets.

Fourth, a long term government commitment and program of incentives may be needed to ensure that the market for solar energy, environmental technologies, and use of hydrogen will be allowed to develop free of short term manipulations of the price of oil that would tend to drive out renewable energy and clean energy systems.

5. If applicable, please explain if foreign investments in similar technologies have adversely affected US competitiveness in the market area of your expertise and how you view the future of foreign competitiveness in the same regard.

McDonnell Douglas invested tens of million of dollars in the Dish Stirling in the early 1980s to produce what is generally recognized as the world's most efficient solar power system. During the divestiture of our solar concentrator systems, we sold one of our dish concentrators to a Japanese firm. It is our understanding that this concentrator is being tested with a Japanese Stirling engine, and that several Japanese companies are conducting substantial development work in this area; for example, we have heard that 200 engineers are working in Japan on the Stirling engine. If true, this activity on their part poses a possible competitive risk to U.S. efforts. If we prove that the Dish Stirling is cost effective and begin to penetrate the electric utility market, Japanese companies would likely follow, using their own technology, as well as reverse engineering of the technology we have sold to them. Substantial investments in infrastructure, technology, and capital would be required to fend off a concerted penetration pricing strategy on the part of the Japanese to capture this potentially huge U.S. and foreign market. Other international solar technologies are not as far along, at least in the Dish Stirling area, although some past work has been done in Germany that may pose some competition in the concentrator area.

Assessment and Recommendations

Based on our past background and more recent studies, it is our assessment that the potential exists for developing refinements to these promising solar thermal electric power systems, such as the central receiver and the Dish Stirling, which could meet the requirements of electric utility companies, especially in the Sun Belt area of the U.S. Therefore, we recommend that serious consideration be given to further development of these promising options. If proven cost competitive with existing forms of electric power production and deployed to capture a significant percentage of the additional electrical power needs of the U.S., these solar energy systems could also offer well known advantages, such as a decrease in air and water pollution, decrease in global warming and ozone depletion, and a lessened dependence on foreign oil imports. Further, the development of an indigenous solar power industry could provide the U.S. with a valuable export to help offset trade imbalances. This industry would promote growth of jobs and opportunity in both the high technology and manufacturing sectors of our economy, and would help us retain and nurture key technology and manufacturing capabilities developed within the defense and aerospace industry, as well as the automobile and electronic industries, which could contribute their manufacturing expertise.

However, there are both risks and uncertainties associated with the selection and development of the most appropriate solar power system, such as the overall system life cycle costs; levelized energy cost competitiveness relative to traditional and alternative forms of power production; electric utility companies' acceptance of these systems; loss of the potential global market to foreign competition; the optimum degree and form of government participation; actual environmental benefits, including the associated health and economic aspects; and viablility of applications in other potential markets, such as toxic waste disposal and production of hydrogen for use in a hydrogen economy. Therefore, consideration should be given to the following:

1. Establishment of an overall, strategic, consistent, and long-term government policy regarding the production of alternative energy in the U.S.

2. Establishment of a government, industry, and utility forum to address the underlying issues of determining which of the various forms of solar energy systems are most appropriate and which can meet the performance, cost, and life requirements imposed by the utilities and by associated industries. It would also be important to consider the economic externalities associated with the production of power by all methods in order to determine the economic, societal, and environmental costs not normally borne directly by the power producers or rate payers. A possible model of this forum is the Interagency Advanced Power Group (IAPG), which has helped federal researchers since 1960 in advanced power information exchange. Members include the US Army, Navy, Air Force, the Department of Energy, and NASA. The Solar Working group is one of seven groups organized by the IAPG to promote infromation exchange among federal researchers and industry in special areas of advanced power research.

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3. Establishment of pilot manufacturing facilities with state of the art high rate manufacturing capabilities to produce the solar energy system components and assemblies at realistic production rates and costs. These facilities would allow the production costs to be accurately assessed, and could reduce the total costs of the demonstration solar power plants. They could also promote use of advanced manufacturing technologies.

4. Establishment of a series of early, near full scale demonstration pilot plants for power production by the most promising solar electric systems.

5. Consideration of the potential for incorporating an alternative energy policy together with defense conversion issues. For example, use of existing infrastructure and personnel associated with Department of Defense, Department of Energy, and NASA laboratories, centers, and bases, together with the defense aerospace industry, could provide positive benefits, especially in the face of downsizing, while helping us to retain and develop certain dual civilian and military technology capabilities.

6. Continuation of relevant and effective government programs, primarily in the Department of Energy, but also in the Department of Defense and NASA, which are associated with the development of technologies related to the use of various forms of solar energy and other alternative energy systems.

7. Encouragement of industry, university, and utility programs to develop and assess alternative energy systems, through such means as grants, contracts, cooperative research and development agreements, and tax incentives.

We are once again at a cross roads regarding how this nation will deal with the vital issues of energy production and use. We have faced global economic instability in the price and availability of oil and natural gas; it was an important contributing factor to our own economic recession. But then there were ample solutions available, such as energy conservation, energy curtailment, improvement in energy efficiency, and substitution of energy resources, as well as the availability of oil and natural gas from domestic and competing foreign sources. Government policy actions at that time also played a key role in eventually bringing about a more stable, and acceptable, pricing structure. However, we have already exploited much of the potential of these past solutions. Also, it is widely accepted that dependence on oil, coal, and natural gas resources cannot be continued for more than several decades, nor can the environmental, health, and economic issues associated with this dependence be left unresolved.

McDonnell Douglas can provide the benefits of our experience, based on our past efforts, and our technical capability to assist in considering and resolving some of these issues. The company therefore stands ready to participate in those activities associated with a national policy on alternative energy research and development which are consistent with our corporate capabilities and our responsibilities to our stake holders.

WRITTEN STATEMENT OF

DR. PATRICK W. RYAN

ON BEHALF OF

ARCO

BEFORE THE

UNITED STATES SENATE

ENVIRONMENT AND PUBLIC WORKS

SUBCOMMITTEE ON TOXIC SUBSTANCES

AND RESEARCH AND DEVELOPMENT

REGARDING

DEVELOPMENT OF

RENEWABLE ENERGY SOURCES

MARCH 22, 1993

Written Testimony
Dr. Patrick W. Ryan
Corporate Consultant
Atlantic Richfield Company (ARCO)
March 22, 1993

ARCO views oil as a versatile energy source that figures to be available for many years at very reasonable prices. Oil is also critical to our economy. As a percentage of total energy use, oil is declining but is still our most important fuel, irreplaceable in many applications. Of the approximately 190 million cars and trucks operating on our highways, 98% run on gasoline or diesel fuel. These vehicles are not simply going to disappear with the introduction of alternative fuels. Neither are the jets operating on kerosene, the ships burning bunker oil or for that matter the millions of houses along the Eastern seaboard that heat with oil.

There has been a great deal of enthusiasm for the notion that renewables and fuels like natural gas will come to dominate the transportation marketplace over the next 20 to 30 years. But even the most enthusiastic advocates of natural gas must realize that gas will never displace more than a fraction of the oil market - and there's no reason why it should. Gas has its own market, largely for home heating and as a boiler fuel, and this market is expanding at a rate that makes gas the fastest-growing energy source in the country.

There has also been much debate about the use of alcohols as the dominant replacement alternative. However, the best use of alcohols in transportation fuels is not as a pure fuel but in the form of oxygenates used in reformulated gasoline.

People who think you can displace nearly 200 million gasoline or diesel engines with ones powered by natural gas or some other alternative are simply being unrealistic. If anything is going to displace gasoline, it will be some form of technology that is not yet fully realized. Widespread use of any such new technology appears to be some time in the future. These technologies could well be battery-powered electric vehicles and/or hydrogen fuel cell systems. Two attachments outline the viability of these technologies.

One of the prime reasons cited by advocates for alternative fuels is that replacement of gasoline will result in a substantial environmental benefit. However, we believe the environmental concern about oil is overstated when weighed against the economic benefits. Thanks to improvements in cars such as catalytic converters and cleaner burning gasolines, air pollution from vehicles has been significantly reduced and will continue to improve as a result of the Clean Air Act. ARCO has been a leader in the development of emission controlling reformulated gasolines. We have been selling our EC gasolines since 1989 in Southern California and the air in the Los Angeles Basin, while still in need of improvement, is as clean as its been in 30 years.

ARCO has spent the last 4 years developing its reformulated gasoline as an economic and environmentally sound alternative. The development of EC-X, an experimental reformulated gasoline, was influential in demonstrating the technical feasibility of California's stringent gasoline standards for 1996. Even at a cost of approximately 15 cents per gallon more to produce than conventional gasoline, it can still compete with any alternatives on the market. Yet, much of this work on the development of new, cleaner gasolines, while recognized in Clean Air legislation, was passed over in the development of the National Energy Policy Act. As a result the Act will provide increased incentives and subsidies for alternative fuels programs while overlooking the benefits of reformulated gasoline.

It is now time for the energy strategy to refocus. The long term goals need to be energy efficiency, true energy security and the best environmental characteristics achievable. ARCO has, for some time, expressed a concern that these long term needs of the country were not getting resolved with the existing energy policy. (See the attached report "Mandating a Transition to Alternative Transportation Fuels: Economic, Environmental and Energy Security Implications". Montgomery, W. D., Sweeney, J. L.).

We have evaluated the various alternatives and their potential as transition fuels and long term replacements. To establish an overall comparison of the fuel options, each individual fuel was ranked on common bases including cost, energy efficiency, security, environmental emissions, technical constraints of manufacturing, and infrastructure availability. The final assessment is presented in Figure III and is consistent with the conclusion that reformulated gasoline is the best transition fuel and electric vehicles and hydrogen fuel cells appear to be viable as long term alternatives.

ARCO believes there needs to be an intensive effort to identify and evaluate alternative long term technologies. For any of these fuel technologies to become viable, the costs must be improved, infrastructure issues must be addressed, and technology constraints must be overcome. Therefore, more effort needs to go into research and technological achieving breakthroughs necessary for the smooth transition from the bridging fuels - primarily reformulated gasoline - to the next big step.

ARCO recommends a threefold approach. First, deemphasize the development of flexible fuel vehicles and the use of alcohols except as oxygenates for reformulated gasolines. Second, redirect support so investments will be made in reformulated gasoline for transition fuel purposes. Finally, invest in research programs of candidate technologies such as electric vehicles and batteries, hydrogen generation technologies including solar hydrogen systems, fuel cell programs, and infrastructure programs for EVs and hydrogen fuel cell systems. As an example, ARCO is funding transportation studies like the University of California, Davis effort which is evaluating and developing future technologies and identifying societal constraints and benefits.

Attachments:

1. Figure I, II, III: Alternative Fuels Identification and Ranking Summary
2. ARCO EC-X - An Emission Control Breakthrough
3. Mandating a Transition to Alternative Transportation Fuels: Economic, Environmental and Energy Security Implications. Montgomery, W. D., Sweeney, J. L.
4. Summary Presentations: Hydrogen and Electric Vehicles

Figure I

ALTERNATIVE TRANSPORTATION FUELS

Now	Alternative Transition Fuels Cut I		Alternative Transition Fuels Cut II		Future
Gasoline	Methanol				
	Ethanol	----------->		--------->	
	CNG				
	Reformulated				
	Electric				
	Hydrogen				

FIGURE II

TRANSPORTATION FUELS

RANKING SUMMARY

FUEL	COSTS	ENERGY EFFICIENCY	SECURITY	ENVIRONMENTAL EMISSION	TECH. CONSTRAINTS MANUFAC. VEHICLE	INFRA-STRUCTURE	OVERALL RANKING
METHANOL	2	3	3	2	2	2	14
ETHANOL	3	4	1	1.5	3	2.5	15
CNG	1	3	2	2	1.5	2	11.5
REFORMULATED	1	2	2	2	1	1	9
ELECTRIC	2	1	1	1	3	3	11
HYDROGEN	4	1	1	1	4	2.5	13.5

FIGURE III

ALTERNATIVE TRANSPORTATION FUELS

NOW	ALTERNATIVE TRANSPORTATION FUELS CUT I	ALTERNATIVE TRANSPORTATION FUELS CUT II	FUTURE
GASOLINE	METHANOL		
	ETHANOL	CNG[1]	REFORMULATED
	CNG/LPG	REFORMULATED	ELECTRIC[2]
	REFORMULATED	ELECTRIC	HYDROGEN[3]
	ELECTRIC	HYDROGEN	
	HYDROGEN		

1. CNG FILLS A NICHE ROLE IN FLEET OPERATION
2. ELECTRIC REQUIRES TECHNOLOGY BREAKTHROUGH IN BATTERIES AND/OR FUEL CELLS
3. BREAKTHROUGH IN SOLAR, FUEL CELL, AND STORAGE TECHNOLOGY REQUIRED

Prepared Testimony For U.S. Senator Harry Reid's Hydrogen Hearing
Roy McAlister, President of the American Hydrogen Association

BACKGROUND:

The American Hydrogen Association is an organization of unpaid volunteers representing virtually every age and walk of life. We are united by the belief that the Industrial Revolution can evolve into the Renewable Resources Revolution. We believe that the technologies of the Industrial Revolution can be applied in the Renewable Resources Revolution to bring about prosperity without pollution. The mission of our organization is to promote *prosperity without pollution*. Our charter for achieving this mission is centered on education and scientific demonstrations.

We have questioned the Industrial Revolution because it has been predicated on fossil fuels. The harder we work in the Industrial Revolution the less coal, oil, and natural gas we have. And, the less clean air and water we have.

Depletion of resources causes inflation and conflict in our supply-and-demand economy. This depletion/inflation syndrome leads to economic hardship and suffering. As we deplete fossil reserves we impair our health and suffer from diseases traceable to hydrocarbon combustion contaminants from our industries and transportation system. Health care expenses traceable to pollution of the environment exceed the cost of fuel burned by our cars and industries.

Our planet's atmosphere acts as a giant heat engine. Energy is trapped in the atmosphere by additions of carbon dioxide. Today there is about 30% more carbon dioxide in the atmosphere than at any time in the last 160 thousand years. As more energy is added to this heat engine it does more work in the form of floods, hurricanes, and tornados. We have suffered the ravages of record-setting floods, hurricanes, and tornados that are powered by this 30% increase in carbon dioxide in the atmosphere.

We have increased the world's population and dependence on fossil fuels to the extent that we burn the fossil equivalent of about 180 million barrels of oil each day. Record setting weather extremes are evidence of abnormal solar energy collection by the atmosphere as a result of burning hydrocarbons as we search for the good life.

But along with these difficult problems, the Industrial Revolution has brought tremendous technological advances. In the last 200 years we have advanced at an exponential rate and provided over 90% of the scientific discoveries and technology developed by humans. Many of these technologies facilitate adoption of renewable resources. Re-directing our engineering and manufacturing excellence to renewable resources will bring about prosperity without pollution.

Hydrogen is the common denominator of the Renewable Resources Revolution. It is the smallest atom but the most plentiful element in the universe. In our own solar system over 90% of the matter is hydrogen. Even on the small speck of crusted iron hurtling through space that we call earth, hydrogen is plentiful. It is most often found as H_20 or water. 70% of our planet is covered by water or ice.

Our bodies and all other forms of life are made up of cells that operate on water chemistry. From conception to death we operate on chemical processes that use hydrogen as the currency. Photosynthesis is based on splitting water into hydrogen and oxygen by solar energy. Green plants use solar energy to derive hydrogen from water. Oxygen is released by green plants in this process. All life on earth depends upon hydrogen chemistry.

EXPECTED BENEFITS OF THE HYDROGEN ECONOMY: Benefits of adopting hydrogen as a replacement for hydrocarbons include the following:

1. **JOBS.** We need to be producing Solar-Engine Generators (such as Stirling Dish Gensets) and Wind Generators at twice the rate that automobiles are manufactured. It will take thirty to fifty years to manufacture enough of these renewable energy conversion devices to replace the hydrocarbons that our nation burns. For this part of the task, job requirements are about the same as for manufacturing automobiles.

   Many additional jobs are indicated for converting the present infrastructure to operation on renewable resources. Not even a war economy could provide as many jobs as are needed to launch the Renewable Resources Revolution. But, the result of the Renewable Resources Revolution can be prosperity without pollution.

   * More new jobs than the present automotive sector.

   * Additional jobs to convert the present infrastructure to renewable resources.

2. **IMPROVED INFRASTRUCTURE:** Renewable electricity from Solar-Engine Generators and Wind Generators will be distributed by expansion of the present electric grid system. Presently established utilities can retail this perpetual supply of electricity. Hydrogen can be produced by electrolysis and stored in depleted natural gas and oil formations. Renewable electricity can be wheeled by the grid from solar-rich areas to water-rich areas for production of hydrogen. Hydrogen can be transported by adding it to natural gas and distributing it through existing natural gas networks. Presently established oil and natural gas companies can distribute and retail this perpetual supply of hydrogen.

   * The present infrastructure can produce more economic goods ... but by using hydrogen it will be without pollution.

   * Entrepreneurs, competition, and tax incentives will spur progress.

3. **IMPROVED TRANSPORTATION SYSTEM**: Hydrogen can be used in the world's present fleet of 400 million cars, buses, trucks, aircraft, and trains. Cars using hydrogen can actually reduce atmospheric concentrations of unburned hydrocarbons, carbon monoxide, tire particulates, and diesel soot in polluted cities. A family car can clean enough air to fill about 5 houses each day.

   * The present fleet of 400 million vehicles can be converted to hydrogen.

   * Cars using hydrogen will clean the air.

4. **WELCOME EXPORTS**: We have vast deserts that can produce enough renewable electricity and hydrogen to run Mexico, United States, Canada, and the manufacturing centers of the Pacific Rim. Hydrogen can be liquified and shipped to distant ports without fear of an oil spill. If hydrogen is accidently released it dissipates quickly into the atmosphere and poses no threat of contamination to ocean creatures or beaches.

   * Hydrogen will be exported to industrialized and emerging nations.

   * High technology goods that protect the global environment will be exported.

5. **PEACE DIVIDEND**: Many of our nation's most talented engineers and technicians have been devoted to defense projects. They have developed world leadership in microelectronics, optics, cryogenics, and other essential aerospace technologies. Application of this talented task force on *defense of the environment* along with maintenance of our arms superiority will quickly advance the hydrogen economy. Defense of the environment is one of the greatest peace dividends. It is turning the *lances* of war into *ambulances* to save the environment.

   * Defense Industry momentum will be applied to renewable resources.

   * The peace dividend can be *peace and prosperity without pollution*.

6. **WORLD LEADERSHIP**: U.S. ingenuity, productivity, and environmental concerns must be shaped into meaningful world leadership. Otherwise coal and oil will be burned in exponentially increasing amounts as emerging nations strive for improved living standards. The global environment is already burdened with contamination. U.S. products and technology that protect the environment must successfully compete in the global economy and win the hearts and minds of 4/5ths of the world's population now demanding improved living standards. Saudi Arabia has announced the intention to supply 25% of the world's energy as solar hydrogen. We need to become energy self-sufficient and supply at least 30% of other countries' energy requirements from the deserts of Texas, New Mexico, Oregon, Idaho, Utah, Arizona, Nevada, and California.

   * U.S. renewable hydrogen must compete in the global economy.

   * U.S. hydrogen exports will protect the global environment.

7. **HOSTING THE RENEWABLE RESOURCES REVOLUTION**: We can lead the world in achievement of higher living standards by hosting the Renewable Resources Revolution. We will be the clean-air nation with greatly reduced health-care costs for diseases due to environmental pollution. Carbon and hydrogen will be new cash crops from garbage, sewage, and agricultural wastes. Cars made of high-strength carbon composites will provide greater safety and efficiency improvements that allow a family to economically travel on renewable hydrogen at the equivalent of 100 mpg. These safer, cleaner, better cars will never corrode and they can be recycled. Safer homes will result from fire-protection systems made from recycled polymers. Cleaner industrial practices will be based on hydrogen chemistry.

   * Improved living standards.

   * Better products.

WHAT CAN THE GOVERNMENT DO?

A. Eliminate the National debt by fostering fair competition to produce prosperity without pollution.

B. Set an agenda to achieve U.S. energy independence and development of renewable energy exports.

President Clinton has called for investments that develop jobs. We need investment in projects that produce goods. One of our most important peace dividends is application of our industrial/military technological prowess in *machines of production* rather than *machines of destruction.*

Energy is the one of the most basic ingredients required for production of goods. We need to invest in improvements to Federal and state lands to enable production of renewable energy.

Federal lands in California, Nevada, Arizona, Utah, New Mexico, and Texas should be offered for the development of numerous Renewable Energy Parks that convert solar energy to renewable electricity. Wind-rich areas in states such as North Dakota, Wyoming, Montana, Texas, Kansas, Nebraska, South Dakota and Oklahoma should be evaluated for converting wind energy to electricity.

Energy from America's Renewable Energy Parks will end our dependance on foreign oil and the drain of $1 billion per week from our economy. It will provide a hedge against inflation because there will be no depletion and no speculation about embargoes, wars, or rumors of war. In times of solar- or wind-energy surpluses, hydrogen can be stored in depleted natural gas fields to create a strategic renewable energy reserve. Competitive bids should be solicited for development of America's Renewable Energy Parks.

COMPETITION WILL BRING PROSPERITY WITHOUT POLLUTION

Bidder's proposals for developing the Renewable Energy Parks should be competitively analyzed and evaluated on the anticipated aesthetics of the completed park, environmental impact, and plan to restore the desert after each Renewable Energy Park is decommissioned. Bidders should be directed to present business plans that detail the steps to create profitable businesses while paying reasonable leases or royalties to the Government.

Contractors that win competitive bids will install Renewable Energy Parks that feature Solar Engine Generators, Photovoltaic Arrays, and Wind Generators. It is anticipated that the Renewable Energy Parks will be owned by the Government and operated by private industry contractors that win operating contracts. These Renewable Energy Parks will provide electricity to the existing electric power grid. Hydrogen for applications in transportation and industry will be produced from the renewable electricity.

Development of Renewable Energy Parks will revitalize American productivity through competition. Competition will bring about rapid product improvements as manufacturers fill orders for 15 million new Solar Engine Generators each year to produce sufficient renewable energy to replace fossil resources.

America needs these 15 million new Solar Engine Generators each year for the next 30 years. Developing and operating the Renewable Energy Parks will greatly increase the number of jobs in the U.S. New jobs developed to improve and equip America's Renewable Energy Parks will far exceed the present automobile industry.

Royalties from leases of Federal lands and taxes on sales of electricity and hydrogen produced by these Renewable Energy Parks will provide income to help balance the Federal budget and pay off the National debt. Thriving American businesses and homemakers will be benefitted by having a secure supply of domestic energy.

Great numbers of relatively small, modular, Solar Engine Generators and Wind Generators will greatly improve the probability of electricity availability regardless of threats due to weather, earth quakes, or terrorist attacks. The more we invest in Renewable Energy Parks the lower the price of energy and the greater the supply.

America's Renewable Energy Parks will guarantee that we will never run out of renewable electricity or hydrogen. Energy security will be assured. Competition between bidders that build and operate Renewable Energy Parks will assure steady improvements and dependability as we progress over the next 30 to 50 years towards *prosperity without pollution*.

In closing allow me to direct your thoughts towards helping the American Hydrogen Association in achievement of our primary mission of education. Please see the following appendix of *FACTS THAT EVERY CITIZEN SHOULD KNOW*. With more widespread awareness of these facts we will find better ways to achieve *prosperity without pollution*.

APPENDIX

AMERICAN HYDROGEN ASSOCIATION

Dedicated to the Advancement of Renewable Resources

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FACTS THAT EVERY CITIZEN SHOULD KNOW

Hydrogen can be manufactured by using solar energy and water. It can also be produced from wind energy or hydro-electricity and water. When it is produced from renewable energy based on the sun it is called "Solar-Hydrogen".

Solar-Hydrogen is a non-polluting renewable energy carrier.

Hydrogen burned as a fuel produces only water and traces of oxides of nitrogen. Both are natural in our atmosphere.

Hydrogen could be cost competitive at $0.75 per gallon equivalent of gasoline. (This estimate is based on the thermal conversion of solar energy to hydrogen and mass production of solar gensets.)

Hydrogen is safer than gasoline or propane. Hydrogen is 14-times lighter than air.

If liquid Hydrogen is spilled it will quickly evaporate and leave no pollution.

Hydrogen can be stored at room temperature as a hydride under little or no pressure, and in a volume that is less than if it were a super-cold liquid.

No one had steam burns from hydrogen combustion in the Hindenburg fire in 1937. After the 32-second hydrogen fire above the Hindenburg was over, however, diesel fuel continued to burn. Diesel fuel fell to the ground and burned for many hours.

Existing automobiles could be economically converted to burn Hydrogen fuel.

Burning Hydrogen does not contribute to the Greenhouse Effect.

Going to a Hydrogen-Economy will reverse the Greenhouse Effect.

Hydrogen is naturally produced by plants and animals. Hydrogen is not toxic.

Over $2 worth of carbon products can be made from a gallon of gasoline. The Hydrogen left over could be used in cars that clean the air. We should not deny future generations of opportunities to use fossil reserves to make diamonds, carbon-fiber products that are stronger than steel, and countless other new products.

It is less expensive to move Hydrogen across the continent than an equal amount of electrical energy. It is the safest and most economical choice for moving energy across the oceans.

Hydrogen could be stored and supplied through the same system that now supplies natural gas.

Hydrogen Facts, Page 2 of 2.

A conventional atomic- or fossil-fueled central power plant can deliver only about one-third of the energy in the fuel as electricity.

A substantial part of the expense in building and operating a power plant is devoted to getting rid of heat from wasted energy.

Placing Hydrogen-fueled generating plants at the site where energy is needed provides the opportunity to utilize much of the energy that is now thrown away by conventional power plants.

Because Hydrogen is pollution free, small personal or local power plants could be designed to utilize the energy we now throw away. We could at least double energy utilization compared to present practices.

These power plants could be mass-produced so that the cost per kilowatt will be much less than that of large conventional power plants.

A Hydrogen power plant could supply much of our personal high-quality water requirements. One pound of hydrogen makes nine pounds of water.

A Solar-Hydrogen-powered heat pump could cool your house in summer and heat it in winter.

Hydrogen is the best way to power an electric automobile.

The United States could make the transition to Hydrogen fuel by the year 2010.

Solar-Hydrogen is the only fuel that can make the United States fuel-independent and pollution-free for as far into the future as the sun will shine.

The Hydrogen-Economy will create millions of high-quality jobs in the United States.

Germany and Japan are already ahead of the United States in research and development of Hydrogen fuel and its applications. Mercedes and BMW have experimental fleets of hydrogen-powered automobiles. Japanese automakers are testing hydrogen-powered cars.

Using a small portion of our land area, we can manufacture enough Solar-Hydrogen to supply the entire energy requirements of the United States.

Did you know that any of the following states could eventually be richer than Saudi Arabia by making and selling Solar-Hydrogen? California, Arizona, Nevada, Oregon, Utah, Idaho, New Mexico, North Dakota, Wyoming, Montana, or Texas could provide endless supplies of Solar-Hydrogen for the U.S. and other countries.

SHIFTING FROM FOSSIL FUELS TO SOLAR HYDROGEN

Testimony prepared for the
UNITED STATES SENATE
SUBCOMMITTEE HEARING ON TOXIC SUBSTANCES, R&D
March 22, 1993
Washington, D.C.

By Harry W. Braun
President
HYDROGEN ENGINEERING ASSOCIATES
Phoenix, Arizona

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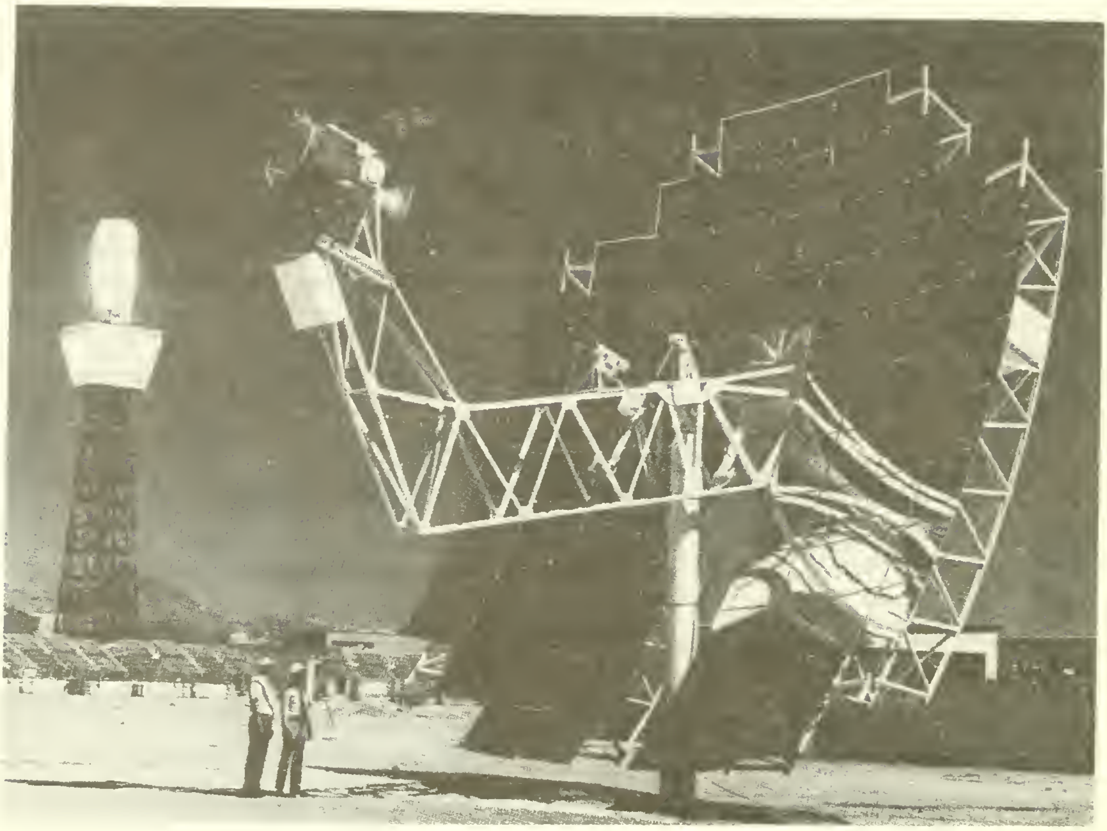

Solar Dish Stirling System

With the much larger Solar One central receiver glowing in the background, two engineers at Southern California Edison's Solar One Test Site near Barstow, California, inspect the first privately-developed 25-kilowatt solar point-focus "Dish Stirling" system. The dish concentrator was developed by McDonnell Douglas Corporation, and the Stirling engine/electrical-generator, which is positioned at the focal point of the concentrator (upper-left center of photo) was developed in Sweden by a partnership of United Stirling/Kockums and Volvo. Stirling engines are also being developed by NASA, Cummins Diesel Engine Company, Detroit Diesel, Toshiba, Kawasaki, Mitsubishi and Aisin Seiki, a major engine and parts supplier of Toyota. Dish Stirling systems presently hold the world's record for converting sunlight into grid-quality electricity, with an overall efficiency of 30% at 1000 watts per square meter of solar insolation. Edison field data indicated Dish Stirling systems were generating nearly twice as much energy per square meter as the next closest competitor, which is the Central Receiver shown in the background of the photo. From a manufacturing perspective, these systems are very similar to automobiles, which means they could be mass-produced in existing automotive industries for large-scale electricity and/or hydrogen production. Under such circumstances, more Dish Stirling systems could be produced than automobiles for many decades. As such, the development of Dish Stirling systems should be prioritized by the U.S. Congress and the Department of Energy as a strategically important technology.

SHIFTING FROM FOSSIL FUELS TO SOLAR HYDROGEN:

A strategy to reindustrialize the U.S. economy while simultaneously eliminating many of the most serious energy and environmental problems

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ABSTRACT

An energy transition to renewable solar-hydrogen technologies and resources would fundamentally resolve many of the most serious environmental problems related to urban air pollution, greenhouse gases, acid rain, gasoline and oil spills, and the destruction of the remaining wilderness habitats. Because of its vast land and solar energy resources, the United States should take the lead in accelerating this energy transition to renewable resources. It is proposed that the United States Congress and the Department of Energy work in cooperation with private industry to develop a reasonable timetable for the establishment of "zero-carbon" emission specifications for all new automotive vehicles.

BACKGROUND

The United States currently spends about $1 billion every week to import oil that is highly polluting and non-renewable. Of all the alternative fuels now being considered to replace gasoline and other hydrocarbon fuels, hydrogen is a prime candidate because it is non-toxic, inexhaustible, and its combustion results in zero-carbon emissions. As such, hydrogen has the potential to make the United States energy independent and essentially pollution-free. Hydrogen-fueled automobiles are already being developed by a number of major manufacturers, including Mercedes Benz, BMW, Mazda and Peugot. What follows is a brief overview of a proposal that will use *private* investment (such as the billions of dollars that the oil industry is planning to spend in Alaska or the Arctic to find perhaps 100 days of oil) to build the factories that will be needed to mass-produce solar-hydrogen energy systems. (For a more detailed overview of this proposal, please refer to *The Phoenix Project: An Energy Transition to Renewable Resources*, which is listed in the references.)

The economic impact of shifting from oil to hydrogen will be profound. Such a reindustrialization effort will improve virtually every industry, every home and every vehicle, and it will allow the United States to once again export rather than import energy. Only a project of this magnitude could realistically pull the United States (as well as the rest of the world) out of the interrelated economic and environmental decline that many people view as inevitable.

Ironically, the largest hydrogen producers in the United States are the major oil companies, which manufacture hydrogen from natural gas and then use it to make gasoline and other hydrocarbon fuels. However, hydrogen is a "universal fuel" that can also be manufactured from water with solar energy, *which is what all of the green plants on the Earth are doing*. Hydrogen can also be extracted from toxic wastes or biomass sources, such as the billions of gallons of sewage sludge that is being dumped into the oceans or the paper and other garbage that ends up in landfills.

A number of renewable energy technologies have been developed in recent years that could be mass-produced for large-scale hydrogen production, including wind, dish Stirling, ocean thermal energy conversion (OTEC) and biomass conversion systems. While promoting "alternative fuels" is a step in the right direction, it also represents a policy of confusion. This is because alternative fuels include methanol, ethanol, oxygenated fuels, propane, butane, natural gas, reformulated gasoline and hydrogen. *Regardless of which alternative fuel is developed on a large-scale, billions of dollars in capital investments will be required by private industry*. Given the current economic environment, it is obviously desirable to make such a transition only once.

The primary obstacles to shifting from fossil fuels to solar hydrogen are primarily economic. Reformulated gasoline, which is expected to cost about $1.50 per gallon, is expected to be roughly half the cost of an equivalent quantity (in terms of energy content) of liquid hydrogen generated from water by electrolysis. However, there are a number of substantial costs associated with gasoline that do not show up at the gas pump. Some examples of external costs include the following:

- A recent Department of Energy report indicated that even a 20% reduction in carbon dioxide emissions would be expected to double gasoline prices.

- The cost of military intervention and the U.S. presence in the Middle East to preserve stability and oil "lifelines" is substantial. In a recent PBS *Nova* television documentary, *"The Arming of Saudi Arabia,"* one analyst indicated that if the total military expenditures were factored into the price of oil, the cost of oil would increase from roughly $20 per barrel to roughly $120 per barrel.

- Fossil fuel energy systems have daunting environmental costs with respect to exploration, transport and end-use. The environmental contamination refers not only to oil and gasoline spills, but to atmospheric pollutants that result from the combustion of carbon-based fuels. According to a Robert MacNeil Newshour report (airing August 6, 1991) on *"Toxic Wetlands,"* a representative from the American Petroleum Institute indicated that if the oil industry had not been excluded from the Toxic Waste Control Act passed by the Congress (which would require the oil companies to clean up the drilling sites), *drilling would have to be halted* because of the high clean-up costs that would be necessary.

- Roughly $70 billion in corrosive damage occurs to buildings and bridges in the U.S. annually due to the acid rain that results from the burning of fossil fuels. This does not include damage to artworks and/or statues, or the ecological damage to forests.

- Medical and health costs that are directly or indirectly related to the use of fossil fuels also represent substantial external costs that do not show up at the gasoline pump. Roughly half of the carcinogenic compounds in the environment come from automotive exhaust, and Robert Zweig, M.D., a specialist in respiratory diseases practicing in Riverside, California, has estimated that if the medical costs associated with using fossil fuels were factored into the price of gasoline at the pump, the cost of a gallon of gasoline could be increased by a factor of 2 to 3.

If these external costs (i.e., true costs) were passed on to consumers when they purchased electricity or gasoline, the free market forces would have ended the fossil fuel and nuclear era long ago.

THE HYDROGEN VARIABLE

Some of the key reasons why hydrogen should be specifically targeted for development by the United States are as follows:

1. Hydrogen is the only combustion fuel alternative that is non-toxic, essentially pollution-free, and inexhaustible. As such, why encourage American industry to waste time, engineering talent and money on developing short-term, non-solution options like methanol or the long list of other carbon-based energy alternatives?

2. Hydrogen is the only energy alternative that can make the United States energy independent. Indeed, the hydrogen energy option will allow the United States to once again become a world-class energy exporter.

3. A transition from fossil fuels to solar hydrogen is being advocated by more than a thousand Ph.D.-level scientists and engineers from 82 countries who make up the International Association for Hydrogen Energy (Coral Gables, FL).

4. NASA and other commercial hydrogen suppliers have documented that hydrogen is safer than hydrocarbon fuels such as gasoline in the event of leaks or accidents. Because hydrogen is the lightest of all elements, it rapidly disperses up and away from people when it is released in the atmosphere.

5. Hydrogen is a critical variable if solar energy is to be used on a large-scale. One of the primary reasons solar technologies are not now being mass-produced is because they are engineered primarily to generate electricity in remote areas. With such small markets, mass-production on any significant scale is not feasible. In addition, most solar resources are intermittent in nature (i.e., the sun goes down at night). As a result, the electricity generated by solar energy systems needs to be stored and transported for later use. Moreover, commercial aircraft and large trucks cannot be operated on electricity alone. They all require a combustible fuel that can be burned in their heat engines.

The U. S. currently spends about $300 billion annually on fossil fuels. Thus, in ten years $3 trillion will be spent on these highly polluting and rapidly diminishing resources. In contrast, if renewable energy technologies such as Dish Stirling systems were mass-produced like automobiles in order to displace the fossil fuels, roughly 400 million of the 25 kilowatt (kW) systems would need to be manufactured and installed. The cost for building and installing 400 million units is estimated to be between 5 to 6 trillion dollars. It is worth noting that the land area required to install 400 million dish systems would be roughly 40 to 50 million acres, which means the entire "dish forest" could be located within the state of Nevada. Assuming 15 million units were manufactured annually (which is roughly comparable to current U. S. automobile sales) it would take roughly 30 years to complete the project.

Zero-Carbon Emission Specifications

The renewable resource technologies are ready for mass-production, but political leadership is needed to organize and initiate this "Reindustrial Revolution." Just as President Roosevelt had to assemble the captains of industry into a War Production Board in order to coordinate the reindustrialization effort for World War II, President Clinton now needs to create a similar industrial Task Force with the objective of making an industrial transition to renewable solar-hydrogen technologies and resources. While such a transition will obviously take decades to complete, the transition needs to begin immediately. If the transition is delayed until the relatively low-cost oil and natural gas reserves are depleted, the ultimate cost of the transition will be expected to increase substantially.

From a legislative perspective, "zero-carbon" emission specifications should be established for all new vehicles after a certain year, such as 2000 or 2010. The existing alternative fuel legislation is confusing and wastes both time and money. Zero-carbon emission specifications, on the other hand, would send a clear signal to virtually all industries about where they should concentrate their limited research and development dollars. Such a strategy would accelerate the transition to renewable solar-hydrogen resources and technologies, which would ultimately provide long-term prosperity without pollution.

SUMMARY

Although shifting from fossil fuels to solar hydrogen systems would resolve many of the most serious energy, economic and environmental problems, the current cost-accounting system that excludes the external costs of gasoline and other fossil fuels makes hydrogen appear to be more expensive than gasoline. As a result, oil companies are continuing to make multi-billion investments in finding the remaining oil reserves, the vast majority of which are located in foreign countries. If zero-carbon emission standards are established by State and Federal agencies, those billions of dollars would instead be invested in the United States in the factories that will be needed to mass-produce the solar hydrogen technologies. Such investments would allow the United States to become energy independent of fossil and nuclear fuels, while employing millions of Americans in relatively high-paying private sector manufacturing jobs that would last for a period of many decades.

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Land Requirements
The shaded area in the state of Nevada is approximately how much land would be required with Dish Stirling systems to make the Unites States energy independent from all fossil fuels (i.e., oil, coal and natural gas).

A Solar Dish Forest

This illustration provides a prospective view of what a large field or "forest" of solar Dish Stirling generator-sets (gensets) might look like. Dish gensets are like "technological trees" (or other green plants), in that they will be able to use sunlight to break water down into hydrogen and oxygen. The hydrogen can then be stored, transported and used as an essentially pollution-free fuel. The illustration was provided courtesy of Hydrogen Engineering Associates (Phoenix, Arizona).

Statement of

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to the

Subcommittee on Research and Development

of the

Committee on Environment and Public Works
United States Senate

March 22, 1993

Thank you, Mr. Chairman, for the opportunity to submit testimony to your subcommittee on the environmental impacts of accelerated research and development in the renewable energy sector. Together, Lawrence Livermore National Laboratory and Sandia National Laboratories, have begun an initiative to demonstrate the technology to produce and use hydrogen for vehicle propulsion and to partner with U.S. industry to support the application of this technology. Our Laboratories have extensive experience in utilizing hydrogen for defense program applications, a lengthy record of broad energy technology development including hydrogen production and storage, and fuel combustion, and proven experience in working with U.S. industry to demonstrate the application of a wide range of technologies. This experience and knowledge convinces us that our Laboratories can play a key role in helping the United States to develop the ability to manufacture, market, and operate cost- and performance-competitive hydrogen-powered energy systems. We believe a major program is required to evaluate and assemble the best hydrogen-based technologies and to integrate these into a demonstration of an operating vehicle or vehicles, with the system to support them, in conjunction with U.S. industry.

The Promise of Hydrogen Energy Systems

The development of alternative fuels that are nonpolluting and that depend on domestic resources is a strategic goal of the United States. Nonpolluting energy systems will mitigate the large amounts of air pollution in our urban environment. Domestic energy sources will work toward removing the strategic burden of dependence on foreign sources and the financial burden of payments to foreign entities that now accounts for over one-half of our balance-of-payments deficit. Hydrogen has a number of features that make it a serious contender for improved transportation systems: it can be produced from a number of domestic sources, it can be used in an engine to significantly reduce emissions while maintaining performance, it is the primary energy source for the production of electricity in a fuel cell, and it can be safely stored and transported. It can also be utilized in nontransportation applications: to store energy from off-peak electricity production, to generate electric power through the use of fuel cells, and as a synfuel for the fertilizer and chemical industries. The fuel cell's ability to efficiently convert hydrogen fuel to electricity makes it attractive as a power source for both electric vehicles and power plants.

The Challenge

The biggest barrier to using hydrogen in the transportation sector is the on-board storage of enough fuel to provide an adequate driving range in an urban environment. Our years of experience in using hydrogen and advanced materials for weapons systems have given us a range of technologies that we believe are applicable to road vehicles and that will provide an adequate vehicle range at acceptable costs. Our analyses indicate that compressed hydrogen gas could be an acceptable form of on-board storage today. We have established a firm understanding of the hydrogen compatibility of materials, a factor that can play an important role in the near-term implementation of gas storage. In addition, there are a number of technologies that show promise for enhancing the range without increasing the cost of on-board storage. Recent advances in materials hold promise for enhancing storage density and, therefore, vehicle range and performance, with improved safety. With our experience with advanced metal hydrides, lightweight high-surface-area adsorbents, and microspheres as hydrogen storage media, we are working to enhance the basic gas storage capabilities of these technologies.

Our experience in the production of hydrogen on a large scale convinces us that hydrogen can be produced at a price competitive with gasoline, especially when the environmental benefits are taken into consideration. Natural gas is likely to be the initial source for significant hydrogen production. Beyond that, the market will determine which sources and technologies are cost-effective. The gasification of biomass, coal, and/or waste offers significant long-term promise in both cost and environmental benefits. Biomass gasification recycles carbon back to the atmosphere from where it was obtained. Gasification of wastes such as oil, sludge, and rubber not only removes hazardous material from the environment but produces a clean fuel that minimizes air pollution. Coal is a significant domestic as well as global resource. When gasified, coal produces hydrogen with the capture of carbon and sulfur, reducing air pollution by two orders of magnitude per ton of coal over what is produced in a standard coal-fired electric plant. The carbon and sulfur byproducts could then be sequestered, or even utilized in limited amounts, to further improve the environmental aspects of coal utilization. This would increase the cost, but by our calculations that cost would be small. Our development, together with industry, of underground coal gasification indicates that hydrogen can be produced with this technology for 85% of the cost of surface gasification and that underground gasification will allow for the utilization of deep and otherwise unmineable coal resources.

Although hydrogen from the electrolysis of water is now too expensive to be competitive, research must continue on technologies for the production of solar thermal electricity and solar photovoltaic electricity. Nuclear power and other sources of electricity are capable of making significant amounts of hydrogen. Direct solar gasification of biomass, waste, and/or coal also need to be studied, along with photoelectrolysis and biophotolysis of water and waste.

The Path to Success

Our experience in field demonstrations of new energy technologies is pertinent to the overriding need to demonstrate the applicable technologies in an operating system. Demonstrations would allow the identification of issues that need to be overcome and would allow the best technologies to be used by industry. The testing of real systems allows a determination of the true operating costs and performance characteristics. There are many energy technologies where we have worked hand-in-hand with industry to carry out full-scale demonstrations. These include solar power generators, windmills, coal gasification, advanced automobile engines, nuclear waste disposal, and enhanced oil recovery. We also have extensive capabilities in combustion research and have maintained longstanding collaborations with automobile and engine manufacturers. Our success in working with industry to produce weapons and weapons components needs no elaboration. Another of the benefits of this weapons work for hydrogen utilization is a safety technology program. Reliable sensors to increase the effective safety of stored hydrogen have been developed.

To achieve the goal of a reliable, cost-effective, and high-performance hydrogen vehicle as an alternative to gasoline use, the nation must have an integrated program with U.S. industries to evaluate the best technologies, to develop those most promising, to integrate these into an operating system or systems, and to carry out demonstrations of these technologies. This is a clear example of the precompetitive generic partnerships of government laboratories with U.S. industry, central to the emerging bipartisan government technology policy. The Department of Energy multi-program laboratories with energy technology capabilities are in a strong position to lead this effort. These laboratories are able to make critical evaluations, to do advanced tests and measurements, and to integrate technologies into demonstrable products.

Such a coordinated program must have a reasonable budget. Present hydrogen efforts within DOE are funded at less than $5 million per year. If fuel cell technology research for transportation is added, another $9 million per year could be counted. We are preparing a program plan for consideration by the Secretary of Energy to accomplish the above outlined goals. We believe that, to be successful, the nation must invest considerably more than is presently going directly to hydrogen research. The $14 million per year may be compared with the current expenditure of $55 billion per year for imported oil.

What are the likely benefits of a successful program? First, a markedly cleaner environment and a higher standard of health for our urban citizens. Second, a significant decrease in our balance-of-payments deficit used for the purchase of foreign oil. Third, American industries that have advanced, environmentally sound technology to market, not only in the United States and the developed nations but also throughout the rapidly developing parts of the world, where urban air pollution is already an issue and will certainly become more of an issue. Aggressive programs for developing hydrogen-powered vehicles are well established in both Japan and Europe, and Japanese concept-vehicles have been shown in the United States.

In summary, we believe that now is the time to institute a broad program to develop and to bring to market hydrogen energy technologies as environmentally benign alternatives to the use of imported fuels. We believe that a program in partnership with U.S. industry to develop the best technologies and then to demonstrate them in vehicles is a necessity if America is to play a role in the burgeoning markets for alternative fuels, especially in the transportation sector.

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