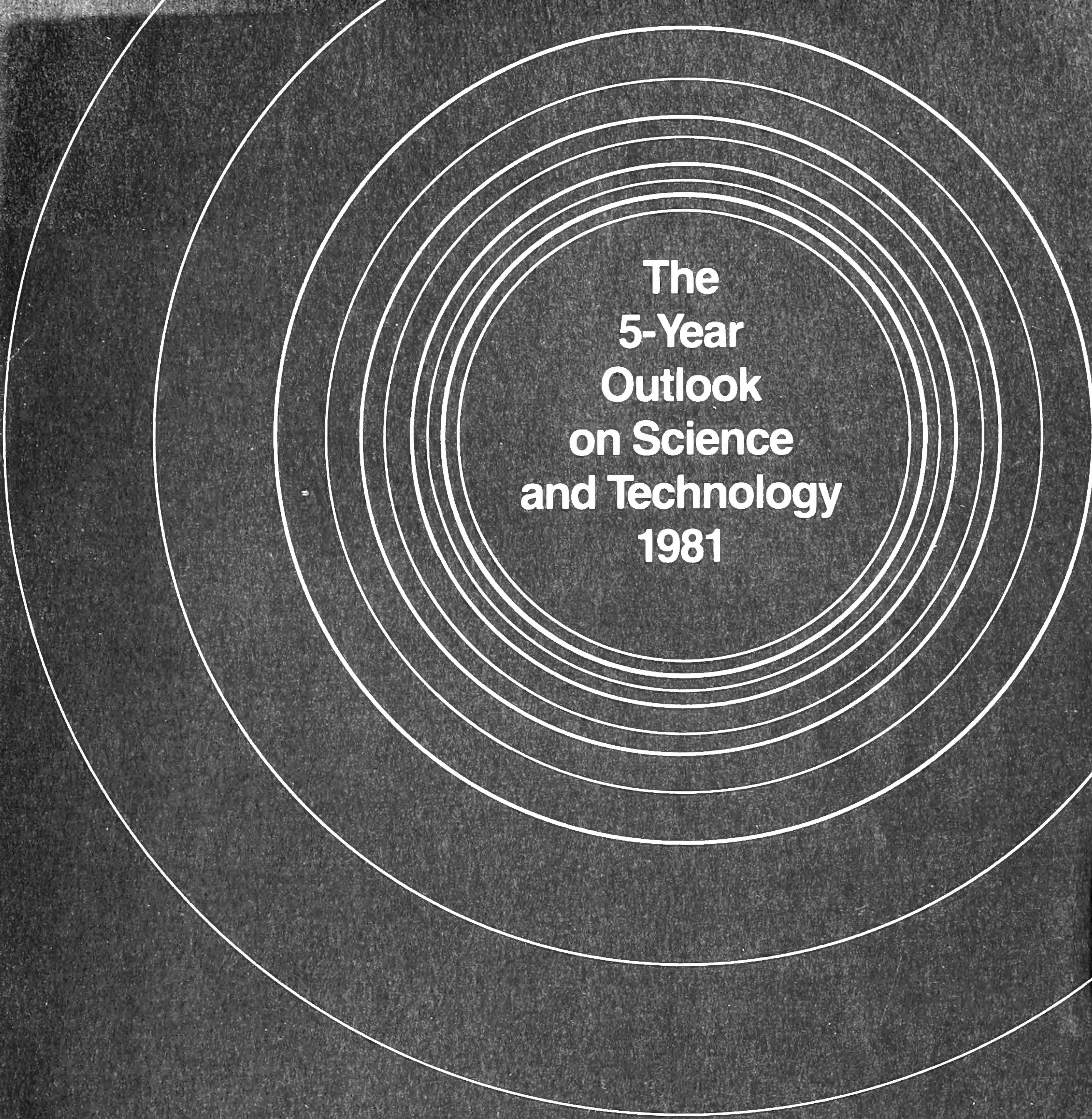

The 5-Year Outlook on Science and Technology 1981

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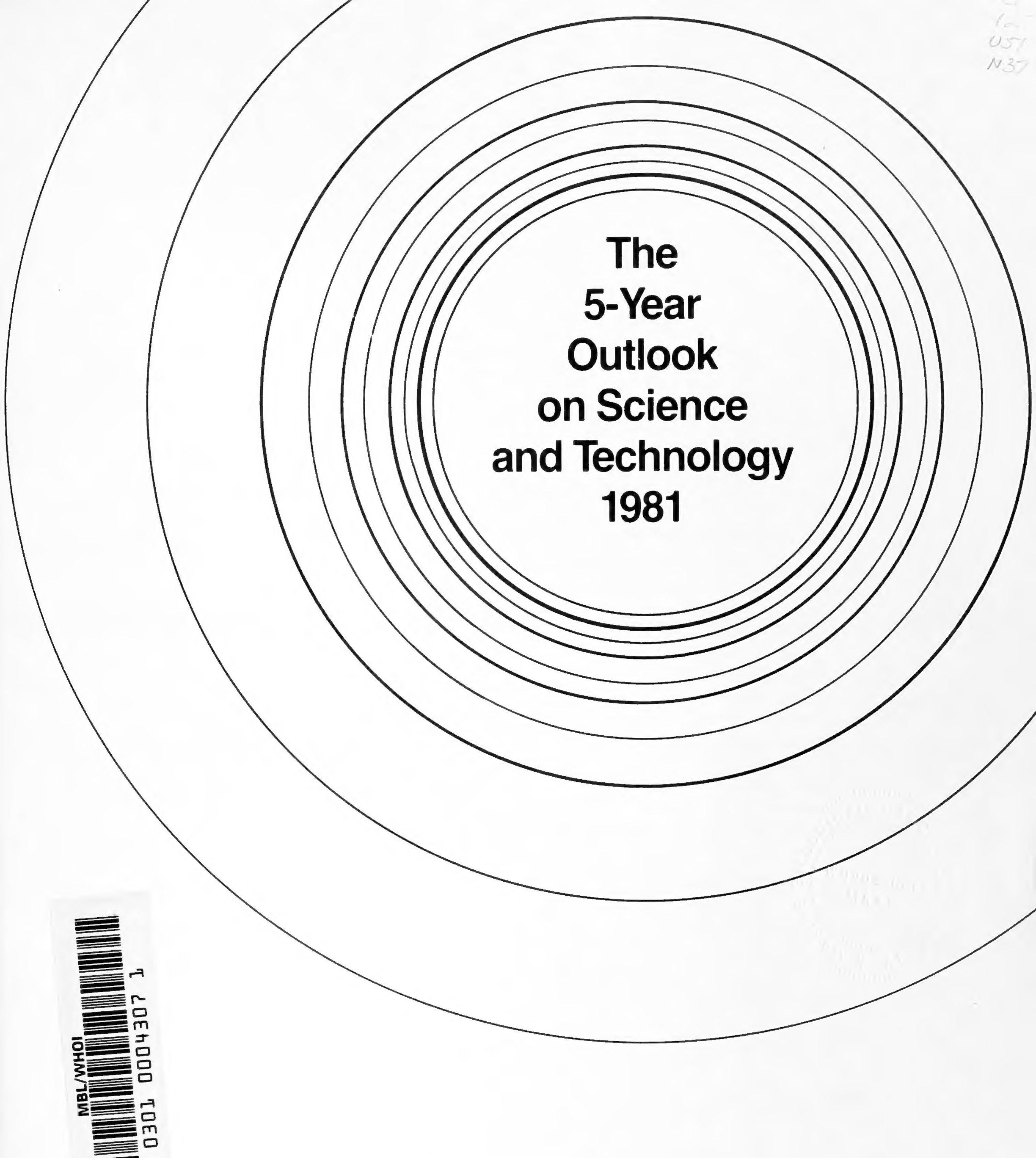

The 5-Year Outlook on Science and Technology 1981

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National Science Foundation

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NATIONAL SCIENCE FOUNDATION
WASHINGTON, D C 20550

OFFICE OF THE
DIRECTOR

January 26, 1982

To the President and Members of Congress:

I am pleased to transmit the second *Five-Year Outlook* on science and technology as required by the National Science and Technology Policy, Organization and Priorities Act of 1976.

This *Five-Year Outlook*, like its predecessor, is based on the premise that discoveries and inventions pouring forth from the Nation's science and technology enterprise will continue to have a profound influence on all aspects of our lives. The report identifies an array of emergent issues that are likely to be of concern to American society during the next five years. It describes some of the problems, opportunities, and constraints associated with the use of science and technology to help define, illuminate and resolve those issues, and it examines several of the problems that may emerge as a result of scientific and technological activities themselves.

In preparing this report, the Foundation obtained the views of a number of scientific organizations, as well as a range of Federal departments and agencies. These contributions, collected in two accompanying *Source Volumes*, reflect the vigor and diversity of American science and technology, and I commend them to your attention. Several themes persist amid this diversity: the shared responsibility of the public and private sectors for maintaining the strength of the Nation's science and technology enterprise; the vital contributions of science and technology to industrial innovation, productivity and economic growth; the changing international context of American science and technology; the need to base an ever-widening range of policy decisions on better scientific information; and the need to improve the level of scientific and technological literacy of all Americans to enable them to participate more productively in our increasingly technological society. Views of Government and non-Government specialists on each of these topics are drawn together in this report and highlighted in its Executive Summary. We have also synthesized their views about likely near-term problems, opportunities and constraints associated with the applications of science and technology in such specific areas as agriculture, energy and the environment, health, national security, and space.

I believe that this *Five-Year Outlook* provides a useful framework for discussion in the Executive Branch, the Congress, and throughout the Nation about the best ways to focus our superlative national capabilities in science and technology to help increase productivity and economic growth, strengthen our national defenses, make more effective use of our human resources, and improve the quality of our lives and our environment.

Respectfully,

John B. Slaughter

John B. Slaughter
Director

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Contents

Preface

The *Five-Year Outlook* on science and technology and its companion, the *Annual Science and Technology Report to the Congress,* are required by Title II of the Science and Technology Policy, Organization, and Priorities Act of 1976 (Public Law 94–282). Both reports are concerned with current and anticipated developments in science and technology and the effects of those developments on society. Both are designed to provide a partial response to the need, expressed by that legislation, for the Congress to be "regularly informed of the condition, health and vitality [of science and technology, and] the relation of science and technology to changing national goals" (Section 102(b)–(6)) and for the executive branch to be able to "identify and assess emerging and future areas in which science and technology can be used effectively in addressing national and international problems" (Section 205(a)–(10)).

Preparation of the two reports is the responsibility of the Director of the National Science Foundation (NSF). Taken in conjunction with the National Science Board's *Science Indicators,* also prepared by NSF, they aim to provide a set of tools useful for policy planning and assessment. More broadly, they are intended as a framework for dialog among the executive and legislative branches of the Federal Government, practitioners and users of science and technology in the public and private sectors, and the general public. *Science Indicators* provides quantitative information, with some analyses, about recent trends in the resources devoted to science and technology and about some quantifiable impacts and outputs of scientific and technological activities. The *Five-Year Outlook* offers a more qualitative and, in some sense, complementary view of present and likely future trends. It identifies and describes current and anticipated developments in science and technology as well as trends external to science and technology that are likely to have impacts on their conduct. The *Five-Year Outlook* also suggests ways in which research can contribute to illuminating and resolving problems of national concern, and it points to constraints on the capacity of science and technology to make such contributions. The *Five-Year Outlook* is not meant to, nor does it, represent the official policies of the U.S. Government. Rather, it serves as an interagency discussion document and a focus for raising problems that might merit policy consideration in the coming years. The *Annual Science and Technology Report,* on the other hand, is a comprehensive statement of the Administration's science and technology policy. It discusses specific issues of concern to the Administration, selected because they are both timely and important, and because the Federal Government has a legitimate and significant role in their solution. The *Annual Report* also reviews Federally supported research and development activities throughout the Government.

The two chapters that compose the body of the second *Five-Year Outlook* on science and technology aim at two different, but related, objectives. Chapter I focuses on the impacts that science and technology are likely to have on problems that transcend or cut across specific substantive fields or areas of application and on the ways in which developments external to science and technology are likely to affect their conduct. Its emphasis is on trends associated with four generic topics that are likely to continue to be important for at least the next 5 years: (1) Maintenance and Development of the Science and Technology Base; (2) Contributions of Science and Technology to Industrial Innovation, Productivity, and Economic Growth; (3) The International Context of U.S. Science and Technology; and (4) Science, Technology, and Policymaking.

Chapter II is concerned with the probable effects of developments in science and technology in specific areas of application. It discusses issues associated with nine functional categories: (1) National Security, (2) Space, (3) Health, (4) Energy, (5) Natural Resources, (6) Environment, (7) Transportation, (8) Agriculture, and (9) Education.

All the broad themes that underlie the discussions in the two chapters are drawn from source materials commissioned by NSF. Other published sources were also used occasionally to provide additional factual information or to amplify the discussions.

The commissioned materials are published in two *Source Volumes*. The first volume consists of 17 chapters prepared by the National Research Council on human resources, natural resources and environment, research frontiers, research systems, and new technologies. The chapters offer the perspectives of individuals active in research in those areas. They do not necessarily reflect policies of the National Science Foundation or the U.S. Government.

The second volume of source documents consists of the views of individuals selected by two organizations—the Committee on Science, Engineering, and Public Policy of the American Association for the Advancement of Science, and the Social Science Research Council. Their contributions deal, respectively, with public policy problems associated with science and technology, and with current developments in social and behavioral science disciplines. Again, the views and opinions expressed do not necessarily reflect the policies of the National Science Foundation or the U.S. Government.

The second of the *Source Volumes* also includes narratives prepared by task groups representing 22 Federal agencies. They deal with anticipated problems, opportunities, and constraints related to science, technology, and public policy from the perspectives of the missions of those agencies. Finally, the second *Source Volume* includes a selected, annotated bibliography of published sources and an index to both *Source Volumes*.

Notes concerning the preparation of the *Five-Year Outlook* and the source materials appear in Appendix B.

Key to Abbreviations

Abbreviations appearing in parentheses throughout Chapters I and II refer to more complete discussions in the *Source Volumes*, to sources contributed to the first *Five-Year Outlook*, and to recent *Science Indicators* and *Annual Science and Technology Reports*. Citations to the published literature appear as footnotes.

Table I—Key to Abbreviations Used in the Text to Cite Source Materials

Abbreviation	Explanation
Nongovernment Sources	
NRC–1,2,3. . . .	Contribution of the National Research Council (in *Source Volume 1*) by chapter number. Note: NRC-Obs. refers to the discussion titled "Observations," by F. Seitz and P. Handler.
AAAS–1,2,3. . . .	Contribution of the American Association for the Advancement of Science (in *Source Volume 2*) by chapter number. Note: AAAS-Obs. refers to the discussion titled "Observations: Racing the Time Constants," by W. D. Carey.
SSRC–1,2,3. . . .	Contribution of the Social Science Research Council (in *Source Volume 2*) by chapter number.
Federal Agency Task Group Narratives (In *Source Volume 2*)	
NS	National Security
SPACE	Space
HEALTH	Health
ENERGY	Energy
GST	General Science and Technology
NR	Natural Resources
ENVIRON	Environment
TRANS	Transportation
AGR	Agriculture
EDUC	Education
IA	International Affairs
Other Selected NSF Reports	
Outlook I	First *Five-Year Outlook*, 1980
ASTR–I,II,III	*Annual Science and Technology Reports:* I = 1978, II = 1979, III = 1980
SI–78; SI–80	*Science Indicators* series: 78 = 1978, 80 = 1980

Executive Summary

America's capabilities in science and technology have provided the basis for its immeasurable contributions to human knowledge about the natural and the manmade universe. The deliberate and systematic application of that knowledge has, in turn, contributed to improvements in the quality of life and the environment, increased industrial and agricultural productivity, economic growth, and national security. Science and technology have provided detailed information and analytical tools to assist in weighing an array of policy options and in assessing the impact of policy choices. And science and technology have become important adjuncts to American foreign policy.

This *Five-Year Outlook* is based on the premise that the unmistakable influence of science and technology on contemporary trends and outcomes is unlikely to abate. It identifies an array of emerging national issues with high science and technology relevance that are likely to confront the United States during the next 5 years. It describes some of the problems, opportunities, and constraints associated with the use of science and technology to resolve those issues, and it examines problems that may emerge as a result of scientific and technological activities themselves.

The issues described in this report have been identified in contributions from the National Research Council, the American Association for the Advancement of Science, the Social Science Research Council, and a wide range of Federal agencies whose missions involve science and technology. Many of the issues are generic in the sense that they transcend or cut across specific substantive fields or acknowledged areas of application. Those issues are identified and described in Chapter I—and summarized below—under four headings: (1) Maintenance and Development of the Science and Technology Base; (2) Contributions of Science and Technology to Industrial Innovation, Productivity, and Economic Growth; (3) The International Context of U.S. Science and Technology; and (4) Science, Technology, and Policymaking. Other current and emerging issues center on problems, opportunities, and constraints that are closely related to particular substantive fields. Those problems, opportunities, and constraints are identified and described in Chapter II—and summarized below—under nine topical headings, each corresponding to one of nine functional categories: (1) National Security, (2) Space, (3) Health, (4) Energy, (5) Natural Resources, (6) Environment, (7) Transportation, (8) Agriculture, and (9) Education.

Generic Policy Issues*

MAINTENANCE AND DEVELOPMENT OF THE SCIENCE AND TECHNOLOGY BASE

The ability of American science and technology to sustain their record of achievement will depend on maintaining and developing the superlative infrastructure established with public and private support since World War II. Retrospective indicators demonstrate convincingly that the United States has maintained its preeminence in scientific research during the past 5 years. But signs of stress, including resource constraints, demographic trends affecting higher education, escalating instrumentation costs, and pressures for short-term returns on research investments, may well become more pronounced during the next 5 years. With respect to technology, the United States is no longer the undisputed world leader, as it was a decade ago, in such basic areas as automotive design, consumer electronics, scientific instrumentation, steelmaking, ship construction, and rail transportation, in part because Japan and Western Europe have reestablished the intellectual and productive capacities that were destroyed by World War II. It is losing its lead in several key defense-related technologies. As yet there is no evidence of any diminution in the inventive capacity of American scientists and engineers; rather, many perceive a failure in following up and implementing their innovations. Yet the above noted stresses, if they do not abate, could seriously erode the science and technology base and therefore its innovative capacity (pp. 2–3).

FINANCIAL RESOURCES

Total (civilian and military) national investments in research and development (R&D) in the United States are greater than in France, West Germany, and Japan combined. The ratio of total annual national investments in R&D to Gross National Product (GNP) declined in the United States since 1967, but it is still higher than in all other countries, with the possible exception of the Soviet Union. The U.S. civilian R&D per GNP ratio has plateaued at about the same level as in the United Kingdom and France, but considerably below that of West Germany and Japan. Moreover, R&D investments in those two countries are more sharply concentrated in areas related to economic growth than is true in the United States (pp. 3–4).

During 1981, total national expenditures for all R&D activities in the United States were estimated to be $69.1 billion, with the Federal and industrial shares estimated at 47 percent and 49 percent, respectively. Of the Federal expenditures, approximately one half were allocated to national security. National expenditures for basic research during 1981 were estimated to be $8.8 billion, with the respective Federal and industrial shares estimated at 68 and 16 percent (p. 3).

Financial resources in the private sector for conducting R&D are likely to remain constrained during the next 5 years, although improved economic conditions are expected to increase prospects for private sector investments. Thus, there are likely to be continuing incentives for structural changes that might facilitate research, including greater use of centralized facilities and cooperative projects between university and industrial laboratories. Cooperation among government, universities, and industry in several defense-related areas of basic science and engineering will likely increase (pp. 10–12).

HUMAN RESOURCES

If present undergraduate enrollment trends persist, there should continue to be enough new graduates in most broad fields of science and technology to satisfy anticipated demands through the decade. However, spot shortages do exist in certain subspecialties, and others may develop. The greatest problems at present appear related to engineers and computer scientists. University faculties, the armed services, and, in some critical fields, private industry are likely to continue to experience difficulties in recruiting and retaining qualified engineers and computer scientists, particularly persons with advanced degrees (pp. 7–8).

UNIVERSITY RESEARCH

At present, universities and colleges and organizations associated with or administered by universities conduct about 10 percent of all the R&D in the United States and about 50 percent of all the basic research. Universities are likely to continue to experience problems related to the costs of carrying out their activities and the decreasing college age population from which undergraduate and graduate students are drawn. Instrumentation obsolescence in such equipment-intensive fields as physics, chemistry, computer science, and the various fields of engineering is likely to continue as a serious problem. Openings for new Ph.D's in many university science departments are likely to remain scarce into the next decade (pp. 8–10).

The numbers of Ph.D's awarded in engineering and computer science have been decreasing since the early 1970s. In contrast, and unlike the situation in most scien-

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*Page numbers in parentheses refer to detailed discussions in the body of the *Five-Year Outlook*.

tific disciplines, undergraduate enrollments in engineering and computer science have been increasing, and applications for admission to programs in those fields are projected to increase. However, unless current faculty recruitment problems are resolved, university engineering and computer science departments may not be able to maintain enrollments at a level sufficient to continue to meet anticipated demand at the bachelor's degree level. In addition, the lack of sufficient numbers of qualified faculty members, coupled with the growing obsolescence of instruments and facilities, could have a negative effect on basic engineering research in the country (pp. 8–10). A similar problem appears to be developing in medical science as a diminishing proportion of young physicians opt for careers in research and teaching. That trend has already led to vacancies on several medical school faculties (p. 49).

INDUSTRIAL RESEARCH

Approximately 70 percent of all R&D in the United States is conducted by private industry. During the next 5 years a good deal of industrial research is expected to focus on improving energy efficiency in processing and on increasing productivity through automation, with the relative importance of those concerns differing among industries and among firms within industries (pp. 10–12).

Since the mid-1960s there has been a shift away from investments in long-range research in several key U.S. industries, a factor that may have contributed to the erosion of U.S. leadership in certain technological areas. Industrial investments in long-range exploratory research during the next 5 years will almost certainly depend heavily on the severity of foreign competition, the general economic situation, and the likelihood that the legal and regulatory climate will not unduly impede the commercialization of results of R&D activities. Changes in U.S. tax laws during 1981 were designed in part to stimulate increased industrial investments in long-range R&D. Industrial laboratories are also likely to seek to strengthen their links to other components of the U.S. research system, particularly universities (pp. 10–12).

CONTRIBUTIONS OF SCIENCE AND TECHNOLOGY TO INDUSTRIAL INNOVATION, PRODUCTIVITY, AND ECONOMIC GROWTH

During the 1970s, the growth rate of American industrial productivity lagged behind that of other industrialized countries, including France, West Germany, and Japan. In addition, the rate of industrial innovation in the United States also appears to have lagged relative to those countries. Total industrial R&D investments in those countries are also increasing faster than in the United States.

CONTRIBUTIONS OF SCIENCE AND TECHNOLOGY

A number of factors influence industrial innovation, productivity, and economic growth. Research and development activities are among the more important, since they underlie the innovation process and provide many of the tools needed for increasing productivity. Productivity growth also appears to be related to long-term investments in basic research; American industries with high ratios of R&D investments to sales have consistently experienced substantially higher productivity growth rates than other industries. There is no evidence of any diminution in the innovative capacity of U.S. scientists and engineers. Rather, low rates of productivity growth in some industries may derive from a failure to make sufficient use of R&D results (pp. 12–16).

Productivity can also be improved by incorporating existing innovations into industrial processes and through the successful application of organizational behavior data, as Japan has demonstrated in the automotive and consumer electronics industries. Additionally, technological innovations based on the results of R&D activities can lead to improvements in the quality as opposed to the quantity of goods and services, although such qualitative improvements are not easily translated into measures of productivity changes (pp. 12–16).

INDUSTRIAL R&D INVESTMENTS

While total real dollar outlays for R&D by private industry have increased substantially since 1975, there has also been a marked shift away from long-term exploratory research toward short-term problem solving in several key industries. Factors beyond the control of industry can discourage long-term R&D investments. They include generally high inflation and interest rates, escalating energy costs, Federal tax and patent policies, and Federal regulations that encourage short-term defensive research and lead to uncertainties about the future marketability of R&D results (pp. 13–15).

The shift away from long-term investments and the failure to capitalize on existing innovations in some industries may also be related to internal management practices, to recruitment procedures that select managers on the basis of business skills rather than technical comprehension, and to a reward system that emphasizes realizing short-term profits rather than investing in long-range innovative potential (p. 15).

THE FEDERAL ROLE

During the next 5 years, the Federal Government is expected to focus on indirect means of encouraging private industry to increase its long-term research investments and on improving the climate for commercializing the results of its R&D activities. In addition to improving the overall economic climate, the 1981 Economic Tax Recovery Act included R&D tax credits, accelerated depreciation schedules, and other incentives to stimulate additional corporate R&D investments. More favorable patent and antitrust policies, as well as removal of disincentives in the form of excessive Federal regulations are also likely to stimulate such investments. Many believe that the appropriate Federal role is to support only long-range, high-risk research with a potentially high payoff. Thus, the Reagan Administration is not expected to support R&D programs of an economic subsidy nature except in areas such as defense and space where Government is the sole or primary consumer (pp. 16, 17).

INDUSTRY-UNIVERSITY COOPERATION

Increased university-industry cooperation appears to be an important element in strengthening this country's R&D enterprise. Such cooperation can take a number of forms, including contracted research, jointly owned and operated research facilities, and university-based industrial institutes. Cooperation offers industry additional access to long-range exploratory research programs as a source of ideas, knowledge, and basic technologies for future innovation. It provides universities with additional sources of research support and gives university faculties and students access to industrial research facilities and a more realistic understanding of both the needs of industry and available industrial research opportunities. The trend toward greater research cooperation between industry and universities appears to be largely independent of direct Federal intervention. Anticipated increases in university-industry cooperative research during the next 5 years should provide data on the effectiveness of various cooperative modes and on the need for catalytic Federal support (p. 17).

THE INTERNATIONAL CONTEXT OF U.S. SCIENCE AND TECHNOLOGY

During the next 5 years, trends and events abroad, particularly in Western Europe, Japan, and the U.S.S.R., will affect U.S. relations with those countries, the conduct of American science and technology, and the relationships of science and technology to U.S. domestic concerns. The Federal Government is likely to continue to support international collaborative efforts in science and technology when such collaborations are clearly in the national interest. Issues associated with international resource management and the global environment will persist on the U.S. domestic agenda, as will the perennial problem of how best to use science and technology to help resolve problems related to poverty throughout the world (p. 18).

INTERNATIONAL COOPERATION

The industrialized democracies, particularly the Western European nations, share many concerns about likely effects of financial and human resource constraints on the conduct of science and technology. Thus, incentives for cooperative international science and technology programs, particularly large, expensive programs of mutual interest and benefit in such areas as space and high-energy physics that are unlikely to provide any single country with a short-term competitive edge, may well increase. Such cooperation is expected to continue under the auspices of official bilateral and multilateral government agreements, through multinational corporations, and through private arrangements between individuals, research organizations, and business firms (pp. 18–20).

INTERNATIONAL COMPETITION

Domestic policies affecting R&D can have serious impacts on U.S. competitiveness abroad. For example, since regulatory policies among the industrialized democracies vary, such American industries as the pharmaceutical industry may be at a disadvantage compared to their foreign competitors. The effects of regulations on international technology competition need continuing examination, on a case-by-case basis, during the next 5 years. Possible effects on U.S. industry of additional tariff barriers or additional high-technology export limitations also need to be examined closely, particularly in view of the vital contributions that R&D-intensive industries are making to the U.S. balance of payments (pp. 18–20).

SOVIET CAPABILITIES IN SCIENCE AND TECHNOLOGY

The U.S.S.R. appears to invest a larger fraction of its Gross National Product in R&D and has a higher proportion of its labor force engaged in R&D activities than any other nation. Soviet scientists have made impressive contributions in several disciplines, and the country has made significant strides in applying R&D in nuclear energy development, civil and military space activities, and national defense. However, the Soviet Union has thus far failed to use its massive R&D investments for fostering innovations in manufacturing industries and for economic growth. Improvements in the productivity of the Soviet labor force have fallen sharply in recent years. The Soviet leadership appears to recognize that with labor, energy, and capital constraints becoming more severe, the country's productivity will have to improve rapidly to meet even its modest economic growth targets; however, Soviet leaders appear unwilling to take the necessary steps to improve productivity. The centrally planned nature of the Soviet economy, the rigid institutional barriers that exist between the R&D and the industrial sectors, and the absence of any strong economic driving force may be difficult obstacles to overcome in stimulating innovation and economic growth (pp. 20–21).

The appropriate degree and form of science and technology cooperation with the U.S.S.R. depends on many factors. The political climate between the United States and the Soviet Union plays a large role in determining the volume of these exchanges, as does the willingness of the Soviets to provide access to their best scientists and facilities. Many U.S. scientists have decided to boycott exchanges with the Soviets over the treatment of their fellow scientists, such as Sakharov, Orlov, and Brailovsky, in the Soviet Union. Past governmental bilateral scientific exchanges have provided the United States with a window into Soviet science, even though the Soviet scientists probably gained more in a scientific sense than their American counterparts. The efficacy of controls on the exports of nonmilitary technologies is also a difficult issue, in part because of the difficulty of prohibiting or limiting access to a good deal of widely available scientific and technical information (p. 21).

RESOURCE MANAGEMENT AND ENVIRONMENTAL ISSUES

Ensuring the availability of oil and other critical raw materials, including metals and certain specialized woods, will continue to be a central problem for all industrialized nations. With the industrialization of several middle-tier countries, it is likely to become a more difficult problem internationally. Thus, there are likely to be increasing incentives for cooperative efforts to apply science and technology to improve mineral resources exploration, recovery, processing, and recycling techniques as well as the development of substitute materials. Cooperative efforts to improve management of the world's tropical forests and prevent or reverse desertification of arid lands can provide both short- and long-term benefits for the United States. Assessments of the causes and probable long-term effects of pollution in the oceans and of increasing fluorocarbon and carbon dioxide concentrations in the atmosphere will also require continuing attention (pp. 21–22).

PROBLEMS OF ECONOMIC DEVELOPMENT

Three related problems will continue to constrain economic development in many less developed countries: population growth, increasing food supply pressures, and escalating world demand for petroleum. At least until the middle of the next century, those problems are likely to be regional rather than global because they will fall more heavily on the poorer countries rather than threatening the carrying capacity of the entire world. Most analysts agree that the United States cannot continue indefinitely to bear the major burden of food production for the world, and that, therefore, agricultural productivity in the less developed countries needs to be increased (pp. 23–24).

One of the most effective ways in which individuals and institutions in industrialized countries can help the less developed countries realize their long-range development objectives is to continue to assist them in building their own indigenous science and technology capabilities. President Reagan recognized the effectiveness of this mode of cooperation in his pledge to devote greater amounts of scientific and technical know-how to third world problems. Such indigenous capabilities are essential for devising new technologies or adapting existing technologies to local needs, for weighing alternatives among available foreign technologies, and for assessing probable impacts of different options for technological development (pp. 24–25).

SCIENCE, TECHNOLOGY, AND POLICYMAKING

The sheer amount of information, including scientific information, available to assist in policymaking processes will continue to grow during the next 5 years, as will the capabilities for handling, manipulating, communicating, and retrieving it. For those reasons, the problems of how to gain ready access to usable data that already exist are likely to become more serious concerns in both the public and the private sectors (pp. 25–26).

METHODOLOGICAL IMPROVEMENTS IN GATHERING AND INTERPRETING DATA

The power of scientific information to help define and illuminate policy problems and assess the impacts of policy decisions has been enhanced considerably through the use of conceptual and analytical tools developed by various scientific disciplines. Methodological improvements are expected to strengthen the reliability of survey results concerned with the characteristics, actions, and opinions of large groups, as well as the validity of demographic projections and certain types of economic projections. Improved methodologies should also permit better interpretation of the data bases that have been gathered systematically for the past 20 years about the current and changing status of various institutions, including industrial firms, educational institutions, scientific organizations, and government at all levels (pp. 26–27).

SCIENTIFIC INFORMATION AND THE REGULATORY PROCESS

During the next 5 years both the public and private sectors will probably make considerable use of scientific information in assessing risks to health, safety, and the environment. A February 17, 1981, Executive Order of the President requires that Federal regulations of hazardous technologies be justified by weighing the costs and benefits of the technologies themselves and of the proposed regulations. Estimating levels of possible damage from a particular pollutant or contaminant can be greatly facilitated by a detailed understanding of fundamental physical, chemical, biological, and physiological processes, a fact arguing in favor of wide-ranging, sustained basic research (pp. 27–28).

Additionally, a good deal of attention is likely to be directed to the uses and limitations of formal risk assessment and cost-benefit analyses and other analytical tools for assessing risks and for weighing risks, costs, and benefits. A particular need is to expand these methodologies to permit comparison of the costs, risks, and benefits associated with entire alternative classes of products or processes—for example, comparison of large-scale coal and nuclear fission systems (pp. 28–29).

Functional Area Problems, Opportunities, and Constraints

NATIONAL SECURITY

Federal outlays for defense-related R&D are expected to continue to increase. The objectives are to develop specific defense-related technologies and to maintain long-range private sector capabilities in such basic science and engineering fields as electronics and materials with the hope that they will lead to long-term payoffs in national defense applications (pp. 31–32).

ELECTRONIC COMPONENTS AND APPLICATIONS

The Very High Speed Integrated Circuits Program of the Department of Defense (DOD) aims to accelerate development of electronic microcircuit technology and ensure the industrial capability for developing the electronics required in the next generation of computers, missiles, radar, and intelligence processing centers. The Defense Department's Ultrasmall Electronics Research Program supports research aimed at revolutionary changes in microelectronics in the next 10 to 20 years that will depend on entirely new concepts and materials (pp. 32–33).

Research in artificial intelligence is scheduled to intensify during the next 5 years, the objective being to establish the basis for intelligent military systems that will provide new capabilities and ease future personnel needs. The use of robots in Department of Defense systems manufacturing is likely to increase along with their use in industry. For the longer term, robots will be developed for field use to assist combat and support forces (p. 34).

Strategic command, control, and communications systems must be able to survive in combat and be highly dependable as the link between the command structure, strategic reserve forces, and troops in the field. Advanced packet communications technologies and a powerful experimental internetwork are being developed to provide local, regional, and long-band computer communications via ground radio transmission, terrestrial circuits, and satellites. The technology for securing classified information processed or stored in computer and communication networks is also being developed (p. 34).

MATERIALS SCIENCE

The availability of stronger, lighter. and more heat-resistant materials is critical to the future development of military aircraft, spacecraft, and ballistic missiles, as well as to many parts of the civilian economy. Research and development that can lead to wider uses of carbon-carbon composite and metal-matrix composite materials show considerable promise. Both of those advanced types of materials have the potential to replace presently used alloys based on strategic metals that the United States must import. Research and development in rapid solidification technology will be vigorously pursued during the next 5 years, with the objective of producing very high quality starting materials for new families of aluminum and titanium alloys and superalloys (pp. 34–35).

AERONAUTICS RESEARCH AND DEVELOPMENT

The integration of advanced electronics and materials technologies is leading to significant improvements in the combat capability of tactical aircraft. New control concepts also provide capabilities to increase the survivability of air-to-ground weapons against ground defenses. A major effort is being made in DOD's advanced turbine engine gas generator program to increase structural testing of promising new turbine engine concepts to provide a base for better implementation of advanced technologies. That effort derives from the need to decrease the cost of propulsion systems by placing greater emphasis on durability and reliability during the research, development, and initial testing stages (pp. 35–36).

SPACE DEFENSE TECHNOLOGY

Advances in laser technology create opportunities for high-energy laser weapons for use in space. Progress has been made toward establishing the technology base for chemical laser weapons, and unconventional laser concepts that equal or exceed the performance of existing devices are being developed (p. 36).

An advanced-test, high-energy electron accelerator, to be completed in 1982, will provide scientific data on the feasibility of propagating stable, high-power, high-energy electrons in the atmosphere over distances of military interest (p. 36).

NUCLEAR TEST VERIFICATION TECHNOLOGY

Research to provide a wider range of sensor options for the detection and identification of nuclear tests will be pursued. A marine seismic system demonstration program should significantly enhance global monitoring capabilities of underground and underwater nuclear tests. By the end of 1983, the program should demonstrate the feasibility of installing and operating the most advanced type of seismic detector in a borehole in the deep ocean floor (pp. 36–37).

HUMAN RESOURCES

The armed services are likely to continue to experience serious problems in recruiting and retaining sufficient numbers of qualified engineers for their advanced research and development programs. Since several of those programs involve cooperation with university research laboratories, faculty recruitment and retention problems in engineering schools are also a serious concern (p. 37).

The Department of Defense is pursuing research in several behavioral science fields to make more effective use of its personnel at all levels. Priority programs aim both at the development of computer-based instruction and training systems and at a better understanding of the interactions between humans and the complex, automated systems that underlie present and future defense capabilities (pp. 37–38).

SPACE

Space has been referred to as the new, limitless ocean. Given the historic impulse to explore, understand, and control uncharted regions, there is no doubt that humans will seek to master space. To ensure that the U.S. space program comprises a logical, efficient, cost-effective sequence of activities, space planning needs to be carried out with a very long range time perspective. During the 1960s, the U.S. space program concentrated on demonstrating both the technological feasibility and the potential usefulness of space flight. The 1970s were a period of consolidation and assessment of the most fruitful directions for future research and application. Space activities in the 1980s are expected to be characterized by more international cooperation and competition and to be more sophisticated in technology, with results valuable for both commercial and military applications (pp. 38–39).

THE SPACE SHUTTLE

Two successful test flights of the Space Shuttle in 1981 opened a new phase in the exploration and uses of space for scientific, commercial, and military purposes. The Shuttle is heavily booked for its early years of operation. Technologies under development aim to increase its payload and stay-time capacities. Planning aimed at implementing the full Space Transportation System is being pursued. That system consists of the Shuttle, the European-developed Spacelab, and upper stages for boosting payloads from the Shuttle's low-Earth orbit to higher orbits. The Shuttle is expected to offer unique opportunities for infrared and optical solar astronomy and, by deploying the Space Telescope, will greatly extend our view into the universe. (pp. 39–41).

REMOTE SENSING AND COMMUNICATIONS

During the next 5 years, increased use is likely to be made of remote sensing and communications satellites. The anticipated transition of the experimental Landsat system to full operational use during the decade emphasizes the desirability of resolving a host of institutional issues at the local, State, Federal, and international levels. High priority should be given to reducing the cost of data handling from remote sensing and communications satellites and to encouraging greater participation by the private sector and by State and local governments (pp. 41–42).

INTERNATIONAL ISSUES

Space offers an attractive arena for international cooperation. At present, 10 European countries under the management of the European Space Agency are developing Spacelab, which will be an integral component of the Space Transportation System, and there could be some continuing cooperation with the Soviet Union in the life sciences during the next 5 years. International competition in civil space applications could also intensify. Ariane, a predominantly French rocket, has, for example, been billed as a potential alternative to the Shuttle for delivering satellites into orbit (p. 42).

Several less developed countries have profited from U.S. communications and remote sensing satellite systems. However, the existence of those systems has also led to demands for a "new information order" that could place severe limitations on transborder information flow.

Additionally, some middle-tier countries are concerned that the rapid deployment of communications satellites into geosynchronous orbits will preempt them from implementing their own research systems. Technologies now being developed for handling increasingly higher data transmission rates to and from communications satellites and for broadening the communications frequency band should partially allay such concerns (pp. 42–43).

HEALTH

There are many indications that advances in, and applications of, biomedical science will continue to contribute substantially to improvements in the overall health of Americans. Genetic recombinant techniques are facilitating the development of a variety of pharmaceutical substances, including new and more effective vaccines and drugs. In the future, the use of these technologies could help control genetic disorders. Advances in the neurosciences, leading to a deeper understanding of the functioning of the brain, could result in substantial progress in the field of mental health. Increased attention to the prevention and cure of tropical diseases will benefit millions of people in developing countries as well as American military personnel stationed abroad (pp. 43–44).

PREVENTION OF MAJOR DISEASES

Death rates from cardiovascular diseases have fallen by more than 30 percent since 1950, due, in part, to the use of more effective drugs and procedures for repairing the heart and blood vessels. The rate of successful treatment of certain cancers also continues to improve. Scientific knowledge of behavioral and environmental risk factors and broadened public awareness of the links between those factors and disease promise substantially reduced incidence of both disorders. However, improvements in the prevention of cardiovascular diseases, cancer, and several other major illnesses will depend upon the collection and analysis of detailed data about specific causal relationships between most major risk factors and major illnesses. Accordingly, there is a high priority need to integrate information about the interplay between behavior, pathological processes, and bodily dysfunction to provide a basis for developing more effective treatment and prevention techniques. In the interim, a variety of approaches are possible to motivate individuals to take more responsibility for their own health by altering their behavior patterns (pp. 44–45).

PROBLEMS OF THE AGED

By the year 2000, the number of Americans over age 65 is projected to increase by nearly 50 percent. Thus, there is an increasing focus on the problem of how to deal with and take greater advantage of the potential of the aged U.S. population. The number of women over 65 is increasing more rapidly than the number of men. Under present conditions, for example, a newborn American female can expect to live 9 years longer than a newborn male. Although some progress has been made—and more is anticipated—in treating such disorders as arthritis, senile dementias, diabetes, and cardiovascular diseases, there is still a relative lack of knowledge about the true functional capacity of the aged and their health care needs. Thus, the potential exists for a considerable improvement in the quality and productiveness of the lives of that population. Two health-related areas requiring particular research attention are the effects of drug metabolism and drug interactions in the elderly, and the debilitating effects of social stresses to which the elderly are subjected, including nursing practices and changes in family and economic circumstances. Additionally, health care and social service strategies need to be devised to maximize the functional and social independence of the aged (pp. 45–46).

ADDICTIVE BEHAVIOR

Alcoholism, drug abuse, and cigarette smoking continue to be major individual, societal, and economic problems. Ongoing research has provided considerable information about the physiological and psychological causes of addiction to cigarettes and marijuana. Research on genetic predispositions and other biomedical factors may offer the first real prospects for advancing knowledge about the causes of alcoholism. Ultimately, the results of those research efforts should lead to improved prevention and treatment strategies, although the effective incorporation of innovative behavioral approaches into such strategies may well require more systematic cooperation between biomedical and behavioral scientists (pp. 46–47).

ASSESSMENT AND DISSEMINATION OF BIOMEDICAL SCIENCE AND TECHNOLOGY

Rapidly escalating health care costs increasingly threaten to constrain the application of advances in biomedical science and, more particularly, biomedical technology. Many new technologies are simply not cost-effective. Hence, we can expect more widespread use of risk-cost-benefit analyses and technology assessments, involving the participation of a broad range of health care specialists, to evaluate the efficacy and possible hazards of medical technologies. Such evaluations will inevitably involve difficult equity questions about the appropriate distribution of health care and the ethical dilemmas associated with the value of human life (pp. 47–48).

The effectiveness of programs to disseminate both biomedical research results and assessments of the efficacy of new technologies to the health care community deserves careful study. By accelerating the incorporation of promising cost-effective biomedical science and technology into the health care system, these types of programs can help ensure a better return on Federal investments in biomedical research (p. 48).

REGULATION OF BIOMEDICAL SCIENCE AND TECHNOLOGY

There is widespread concern that Federal regulations designed to protect medical patients and subjects of research may pose a significant constraint on the implementation of advances in biomedical science and technologies. For this reason, regulatory procedures to protect human subjects of biomedical research are normally administered by local committees of physicians, other health care personnel, and lay persons. The regulations are being substantially revised so that they can provide adequate safeguards for research subjects without unduly inhibiting the research process. Federal regulations associated with testing and assessing new drugs and new medical technologies are subject to intense controversy. Steps are being taken to assure that anticipated compliance costs and regulatory uncertainties do not seriously inhibit the development of many promising new drugs and technologies (p. 49).

HUMAN RESOURCES

While the pressure for admission to medical schools continues unabated, the perennial problem of the geographical distribution of physicians remains. There has also been a diminution in the number of young physicians entering academic medicine, as evidenced, for example, by vacancies on medical school faculties. Continuation of that trend could seriously inhibit further advances in biomedical research and in incorporating the results of that research into the U.S. health care system (p. 49).

ENERGY

The Administration's energy policy is an integral part of the President's comprehensive Program for Economic Recovery and is based on the assumption that, with regard to the development of energy sources, the collective judgment of the market is generally superior to centralized programming. The Federal Government will continue to invest in long-term, energy-related research with high risks and potentially high payoffs. However, it will no longer assume responsibility for accelerating the development of advanced energy technologies, nor will public funds be used to subsidize domestic energy production or conservation (p. 50).

The power of the free market in alleviating short-term energy shortages is suggested by the moderated growth of energy consumption in the United States, and especially in oil and transportation fuels use, that has resulted from higher prices. Energy demand growth through 1990 is now projected to be slightly more than 1 percent per year, well below the 2 percent forecast of 1979. The mix of energy sources the United States will use in the near and more distant future will depend on domestic and international demand for available fossil fuels and relative prices of various alternatives (pp. 50–52).

MAINTAINING PETROLEUM AND NATURAL GAS SUPPLIES

Until industry develops and commercializes competitive alternative fuel sources to supplement declining domestic oil and gas reserves, vigorous pursuit by the private sector of technologies to facilitate the exploration and development of new domestic reserves and to enhance the recovery of oil from existing wells is anticipated. Administration actions to decontrol oil prices and to stimulate the investment climate through regulatory and tax reform should provide the necessary market conditions for these activities. Any undiscovered oil fields in the United States are likely to be in locations with harsh environments that will make exploration and commercial development difficult and expensive. Industry is expected to improve technologies for offshore exploration and drilling operations during the next 5 years. Additionally, field tests, supported by laboratory investigations, are likely to be carried out to improve techniques for enhanced recovery of petroleum from known domestic sources (p. 52).

The prospects for discovering new domestic reserves and exploiting known, unconventional sources of natural gas are considered good. Since domestic natural gas supplies are unlikely to be depleted as rapidly as domestic petroleum, gas could serve as a substitute for petroleum in some applications (p. 52).

UNCONVENTIONAL SOURCES OF OIL

Vast deposits of such unconventional and ultimately more costly fuel sources as heavy oils, tar sands, and shale exist in several countries, including the United States and Canada. They might be exploited if economic conditions become favorable. Plans to proceed with commercial mining and production of fuel from oil shale in the Rocky Mountains have been announced, and future production efficiencies that will reduce environmental problems and use water more efficiently than at present seem possible (pp. 52–53).

SYNTHETIC FUELS

Commercially demonstrated processes are now available for producing usable synthetic gases from coal, and processes with improved efficiency, reliability, and environmental acceptability should be demonstrated in the next 5 years. Private industry has made substantial investments in the development of synthetic fuels technologies. Large pilot plant programs for the direct liquefaction of coal are under way, and these programs could lead to commercially feasible processes by the end of the decade (pp. 54–55).

Probably the greatest need in synthetic fuels science and technology during the next 5 years is for basic science and engineering studies to learn more about different possible production processes and fuel uses. Such studies should lead to improved efficiency and reliability in second- and third-generation commercial plants and to minimized environmental problems (pp. 54–55).

Fermentation of grains to produce alcohol is an established commercial technology. Results of research and development that could lead to the commercial production of alcohol and synthetic gas through fermentation of grains and other biomass forms are promising. A better understanding of plant genetics could serve as a basis for the biological engineering of plants and could greatly enhance the potential of biomass as a significant long-term energy option (p. 58).

DIRECT COMBUSTION OF COAL

Coal use is expected to increase throughout the decade. A number of utilities and a few large industries are already converting from oil to coal or natural gas, and a good deal of attention is being paid to possible commercial systems that would allow the cost-effective use of coal instead of oil in small manufacturing plants. The introduction of new mining technologies should improve the efficiency of coal extraction and reduce the health and safety hazards associated with mining. Increased direct use of coal as a fuel will be facilitated by systems, some of them near commercialization, that reduce the emission of oxides of sulfur and nitrogen. Research on coal combustion processes is expected to lead to further improvements in such advanced systems (pp. 53–54).

Increases in atmospheric concentrations of carbon dioxide may ultimately limit the amounts of fossil fuels, including coal and synthetic fuels, that can be burned. A high-priority need in the next 5 years is to learn enough about the details of the global carbon dioxide problem to provide a basis for assessing probable long-term limits on coal use (pp. 53, 55).

NUCLEAR FISSION

Research and development aimed at improving the efficiency and safety of light water nuclear reactors is expected to intensify during the next 5 years. Science and engineering studies will be focused on an advanced reactor that could be operated in a converter mode fueled with a uranium-thorium mixture. Such a reactor could serve as a source of industrial process heat as well as electricity. Broadly based research and development efforts will be pursued that would permit the selection of an appropriate breeder reactor system for possible deployment by the end of the century. Since the 1977 moratorium on commercial reprocessing and recycling of fuel has been lifted, these reactors, which could use domestic uranium and thorium with 100 times the efficiency of present light water reactors, may now be a more realizable option. Additionally, the existence of reprocessing capabilities could simplify the technical problem of permanent nuclear waste disposal. Reprocessing and recycling are presently being pursued in Europe and Japan. France plans to demonstrate a large commercial breeder reactor during 1983 and has also completed a 2-year waste disposal pilot test (pp. 55–57).

DIRECT SOLAR CONVERSION

Federal tax credits have helped increase the Nation's use of solar energy for space heating. A variety of technologies for harnessing solar energy for other applications are under development. Photovoltaic systems that convert light directly into electricity with better than 11 percent efficiency are at the research stage. Cost reductions, however, may require radically new approaches using advanced semiconductor materials. The introduction of large, automated facilities should also reduce the cost of commercial production (pp. 57–58).

FUSION RESEARCH

The scientific feasibility of producing fusion power by the magnetic confinement method is scheduled to be demonstrated during the next 5 years at test facilities nearing completion, but formidable technical problems remain to be solved if a commercial-size system is to be demonstrated by the end of the century. Development of the inertial fusion method is essential for addressing nuclear weapons design problems. The country's leading inertial research facility is scheduled to demonstrate the scientific feasibility of that method in 1983 (pp. 58–59).

ENERGY END-USE EFFICIENCY

Increased energy use efficiencies will continue to strengthen national efforts to ameliorate the near-term energy problem. Considerable savings are anticipated as increasing fuel prices lead manufacturing industries to replace existing capital equipment with more energy-efficient stock, introduce more energy-efficient processes, and make better use of industrial wastes (p. 59).

NATURAL RESOURCES

Continued increases in the world's population, coupled with rapid industrialization in many middle-tier countries, are likely to exert increasing pressures on the world's natural resource base. Global trends affecting the price of strategic metals could also affect their availability to the U.S. economy. Seasonal water shortages are becoming common in some areas of the country. Desertification of arid lands is a severe problem worldwide and is serious in some areas of the United States. The long-range effects of many resource constraint problems, both in the United States and globally, will depend critically on advances in science and technology and on the implementation of those advances (pp. 60–61).

NONFUEL MINERALS

There will be a continuing need for long-range efforts to ensure the availability of nonfuel minerals vital to the domestic economy, including several metals whose easily accessible, high-grade ores have largely been mined already in this country. The development of new and more sensitive instruments to detect anomalous concentrations of minerals in the Earth's crust, coupled with a deeper understanding of fundamental mineral formation processes, would increase the probability of locating new mineral reserves in the United States. Additional reserves of certain critical metals exist in the deep ocean floor, although the technology for extracting them requires further development. Promising advanced mining and handling technologies and more energy-efficient processes for the primary conversion of mineral ores into metals could improve the international competitive position of the U.S. minerals production and processing sector. The development of advanced alternative materials that could be substituted for scarce imported metals is being pressed by the U.S. defense and space R&D programs and shows considerable promise for the civilian economy as well (pp. 61–62).

WATER SUPPLIES

Seasonal water shortages are common in 20 percent of the 106 U.S. watersheds, and that percentage could double by the end of the century. Water shortages are being exacerbated in the Western States by population shifts and the development of new energy industries. A major program to identify and exploit additional ground water has been initiated by the U.S. Geological Survey, and technologies for decreasing industrial, agricultural, and urban water use have already aided conservation efforts. Demonstration plants for converting seawater and brackish water to useful quality are under construction, although present processes are both expensive and highly energy inefficient. Results of ongoing research aimed at developing less water intensive crops and crops that can grow in highly saline water show considerable promise as a means for reducing water consumption in agriculture (pp. 62–63).

DESERTIFICATION OF ARID LANDS

The sustained decline of the productivity of the world's arid lands is projected to increase by another 20 percent by the end of the century. Agricultural productivity in the United States is also being affected by desertification, although the increased use of chemical fertilizers, water, and herbicides and pesticides has compensated somewhat for declining soil conditions. Research and development on salt-tolerant crops and vegetation, development of economic uses for naturally occurring arid land plants, rehabilitation of degraded lands, introduction of operational desertification monitoring techniques, and improved management of surface- and ground-water reservoirs can further alleviate desertification effects (p. 64).

DISAPPEARANCE OF TROPICAL FORESTS

The rapid disappearance of the world's tropical forests is leading to severe and far-reaching ecological problems. In the less developed countries, where most tropical forests are located, the disappearance also means the loss of a widely used resource. The United States relies on tropical forests as a major source of specialty woods and pharmaceuticals. A coordinated international effort on tropical forest research and management, greatly increased worldwide reforestation, and a detailed analysis of the political, economic, and social consequences of reforestation are regarded as minimally necessary responses to the problem (p. 64).

ENVIRONMENT

Impressive gains in controlling pollution and upgrading the quality of the environment were made during the 1970s. However, the total costs of some of the Federal regulations designed to protect the environment and the ways they have been interpreted or enforced may outweigh the intended benefits. Detailed scientific information on the occurrence and effects of various pollutants and on technical means for reducing or mitigating their occurrence and effects will continue to be needed. Additionally, refinement of the analytical tools for weighing costs and benefits of alternative regulatory strategies will be required to implement the President's February 17, 1981, Executive Order requiring that all Federal environmental, health, and safety regulations be justified by assessing costs and benefits (p. 65).

AIR QUALITY

There is a high-priority need for better information about the relationships between fossil fuel use, particularly coal combustion, and the long-term global climatic effects of increased carbon dioxide concentrations. That information will be vital for long-range energy planning. Some progress has been made in controlling the industrial emissions of sulfur and nitrogen oxides that can lead to acid precipitation. Continued efforts should be directed toward the identification, control, and monitoring of those emissions, and to their atmospheric transport mechanisms, chemical transformations, and environmental and health effects (pp. 65–66). Additionally, continued efforts should be focused on the occurrence, transport mechanisms, and health effects of atmospheric particulates, especially airborne carcinogens (p. 68).

TOXIC WASTES

While several promising technologies for handling toxic substance spills are emerging, including dispersant agents and new bacterial substances used as cleanup agents, the development of more effective technologies to detect, contain, and mitigate the effects of oil and hazardous chemical spills is badly needed. Also needed are better means for transporting, storing, treating, and disposing of the 57 million metric tons of hazardous, nonnuclear wastes produced annually in the United States, and remedial action at the country's 2,000 existing problem disposal sites is an obvious high priority. The hazardous waste disposal problem is being mitigated somewhat by processes that reduce the quantity of wastes at the point of origin and that remove or recover hazardous materials from waste streams during disposal operations (pp. 66–67).

WATER QUALITY

The technology-based uniform national standards approach to controlling municipal and industrial water pollution is expected to achieve marked improvements in point source control, although additional information about the contamination of ground water from those and other sources is needed. The control of emissions from nonpoint sources, which account for more than half of the pollutants that enter U.S. waters, is a much more complex problem whose solution is not yet in sight. Additional research is needed on the environmental and health effects of potentially toxic water pollutants to rationalize existing effluent limitation regulations. Research aimed at improved techniques for monitoring water pollution levels and for reducing the costs of treating polluted water should also be pressed (pp. 67–68).

TRANSPORTATION

During the next 20 years, per capita passenger transportation capacity requirements in the United States are expected to increase at an average rate of 2 percent per year and those for freight transportation at 1⅓ percent per year. While those growth rates are smaller than in the past quarter century, they are still substantial and will require the implementation of new technologies to mitigate a variety of constraints on the growth of the national transportation system (p. 69).

CARRYING CAPACITIES

The entire U.S. transportation system may begin to encounter limits on its carrying capacity during the next 5 years. Such emerging technological developments as ramp metering signalization for highways could aid in reducing highway congestion and improving safety. Current developments in advanced air traffic control, which can automate decisionmaking, should help alleviate increasing limitations on airport capacity and improve the productivity of the U.S. commercial air transportation system (p. 69–70).

The anticipated increase in the use of coal during the next decade will require a considerable expansion in the carrying capacity of western and eastern railroads if they are to serve as the primary distribution system for domestic coal. Slurry pipelines offer an attractive distribution alternative for distances up to 300 miles, and current research on the flow behavior of coal-water mixtures could lead to significant improvements in this coal transportation mode (pp. 69–70).

ENERGY EFFICIENCY

Because transportation accounts for 25 percent of U.S. energy consumption, anticipated future constraints on fuel availability will require increased efficiencies in that sector. During the next 5 years, the greatest energy efficiency improvements are expected to occur in automobiles and commercial aircraft. Conventional gasoline and diesel engines are expected to be more efficient by the end of the 1980s. Additionally, research is being directed toward several longer range developments, including alternatives to conventional engines that might provide still greater efficiencies; batteries that can store up to 10 times the energy of present lead-acid batteries and thereby provide a basis for increased use of electric vehicles; and the efficient use of alternative fuels produced from coal or biomass (p. 71).

IMPROVEMENTS IN SAFETY

The innovative use of radionavigation, radiolocation, radio communication, and computer systems provides opportunities for improving both the safety and the efficiency of air and water transportation. The convergence of computer and communications technologies also provides opportunities for transportation safety improvements through automation in such areas as mass transit and air traffic control (pp. 71–72). In highway traffic safety, most technological efforts to date have focused on postcrash survivability and injury reduction rather than on accident prevention. Such strategies will become more costly and less effective as the United States moves toward the increased use of smaller vehicles, suggesting that a large portion of future advances in automotive safety could come from improvements in driving habits, rather than from further technological refinements (p. 72).

AGRICULTURE

Each American farmer currently produces enough food for 60 people, a significant increase from 30 in 1970, and 7 in 1900. Agricultural products constitute over 20 percent of the total value of U.S. exports, and increases in the world's population are placing new demands on the U.S. food producing system. Yet the rate of increase in agricultural productivity has recently begun to slow both in the United States and elsewhere in the world. That trend emphasizes the need to apply advances in science and techology to ensure the continued availability of adequate input resources for agriculture—namely, water, land, and nutrients—and to increase product yields (pp. 72–73).

INPUT RESOURCES

Growing urbanization and industrialization in the United States and in much of the rest of the world has led to the use of less productive land for agriculture. But the use of less than prime land requires increased use of other input resources, including supplementary nutrients, water, and, particularly, labor. In addition, less than prime land is often subject to more rapid degeneration and erosion. Experiments with multiple cropping, reduced tillage, recycling of agricultural wastes, organic farming, and other changes in cultivation practice have been somewhat successful as alternatives to the extensive use of costly synthetic fertilizers on less than prime land (p. 73).

On the microlevel, the factors that determine the efficiency of nutrient intake processes in plants are just beginning to be understood. Research in progress could provide opportunities for the selective breeding of plants that can absorb and process much greater volumes of nutrients from the same basic source (p. 74).

New irrigation techniques to improve the efficient use of water show considerable promise. The water availability constraint on agriculture could also be mitigated in the long term by ongoing research aimed both at lowering the cost of desalination processes and at the development of plants that can be grown in high-saline or brackish water (pp. 73–74).

INCREASING PRODUCT YIELDS

While selective breeding of agriculturally useful plants is almost as old as human civilization, the current explosion in fundamental knowledge in molecular and developmental biology and genetics, coupled with the development of such new manipulation techniques as recombinant DNA, offers the potential for deliberate engineering of species with a range of desirable characteristics. Advances in genetic engineering and embryology also promise to make substantial contributions to increasing the effectiveness of animal husbandry (pp. 74–75).

The development of plants that can fix nitrogen from the atmosphere rather than having to rely on fertilizers in the soil, that can tolerate more highly saline water, or that are more resistant to pests and parasites shows considerable promise. Research that could yield synthetic versions of the growth regulators that determine the development time of plants is also receiving considerable attention. Such synthetic growth could be used to accelerate crop growth cycles (pp. 74–75). Genetic engineering techniques are being used to improve the ability of plants and animals to withstand environmental stresses (variations in rainfall, nutrient supply, and temperature), thereby expanding the range of lands where cultivation is possible (p. 75).

Sophisticated analytical methods are also leading to an improved understanding of the nature of biological susceptibility to disease and the spread of disease (p. 75).

More broadly, there is a critical need to understand the systemic relationships of plants to their total environment. Advances in that understanding have led, for example, to the integrated pest management concept that relies on combining information about the biology of pests, the environment, and the host to obtain maximal results from the application of biological and chemical controls. A better understanding of such systemic relationships is also essential to the prevention of the spread of plant disease, since major epidemics are almost always the result of transferring plants from one biosystem to another. Improved knowledge about the relationships between plants and their total environment will also be needed to engineer plants that are better able to cope with effects of changes in atmospheric conditions, including pollution caused by acid rain (p. 75).

EDUCATION

Science and technology are intimately linked with education. The strength of a country's capabilities in science and technology is closely coupled with the quality of education, at all levels, in mathematics, science, and technology. In addition, science and technology offer powerful tools for use in the educational process.

ELECTRONICS TECHNOLOGIES

Modern computer and communications technologies offer a wide range of possibilities for innovative instruction and evaluation, and thus for developing more flexible educational strategies. The relatively low cost of sophisticated computers provides the potential for adapting curricula to different local conditions and for tailoring instruction and evaluation to the needs of individual students and teachers (pp. 77–78).

There is as yet little evidence that the modern electronics revolution has had much impact on the formal educational system. Rapid changes in the state of the art have been one inhibiting factor. The extensive use of advanced electronic technologies for training military personnel and for continuing education in business and industry may provide lessons and guidelines for the formal educational system. However, realizing the full potential of those technologies in the classroom would necessitate a considerable restructuring by State and local authorities of educational strategies and methods, including considerable teacher training and retraining (pp. 78–79).

INSIGHTS FROM COGNITIVE SCIENCES

Current research in the cognitive sciences, particularly on the interactions of humans and machines and the acquisition of cognitive skills, could be used to plan effective strategies for adapting modern electronic capabilities to classroom use. Research is also yielding insights on problem-solving processes and on cognitive and social development in children. Those insights should find broad applicability in teaching, with or without electronic assistance. Again, current applications of cognitive science research in the military sphere could provide useful information for the formal education system (p. 79).

EDUCATION IN SCIENCE AND TECHNOLOGY

Current and emerging problems associated with the supply of and demand for qualified professional scientists and engineers are highlighted above (Generic Issues—Maintenance and Development of the Science and Technology Base). The educational requirements of technicians who support the activities of scientists and engineers and of others whose jobs demand more familiarity with modern technology are also changing, as advances in technology increase the complexity of U.S. society. The intrusion of science and technology into virtually every sector of society suggests that a reasonable degree of science and technology literacy will be increasingly important in all phases of our lives (pp. 79–80).

The primary and secondary school curricula of several industrialized countries, including West Germany, Japan, and the Soviet Union, focus heavily on science and mathematics. In contrast, the trend in the United States during the past two decades has been a declining emphasis on those subjects. A significant reversal of that trend, which could have serious long-term consequences for the strength and vitality of the U.S. science and technology base, will require extensive cooperation between the scientific and engineering communities and the State and local authorities who have responsibility for precollege education in the United States (p. 80).

I Generic Policy Issues Associated with Science and Technology

A. Introduction

The support of scientific and technological progress has become a necessity for modern industrial societies. Although the proposition is sometimes disputed, most thoughtful analysts have concluded that world society has reached a stage where continuing and even accelerating progress in science and technology are necessary conditions for avoiding social, economic, and environmental regression in the future. This does not mean that science and technology are sufficient conditions. They must be used in a wise and foresighted manner, and that depends more on political and social arrangements than on science and technology themselves. However, the premise of this *Five-Year Outlook* is that scientific and technological progress and its wise exploitation are indispensable adjuncts to modern society.

Any assessment of the outlook for science and technology must recognize the interdependence of science, technology, and society. Science is driven largely by its own internal imperatives, as dictated by the new opportunities and advances within the conceptual structure of the disciplines. But to an important and increasing extent, science is also driven by society's search for solutions to some of its greatest problems and needs. Technology is the primary link between the internal and external determinants of scientific progress. Technological development incorporates knowledge derived from science into usable processes and products and, increasingly, scientific and technological factors form a base for the development of public policies for enhancing the environment and the quality of life. Technological progress also stimulates further scientific advances both by defining new problems that can be illuminated by scientific research and by providing the requisite instruments and tools. As in the past, the state of the U.S. science and technology enterprise during the next 5 years will be conditioned by trends in both the internal and the external determinants of technical progress and by the relationships between them.

Several external factors help determine the pace and direction of advances in science and technology. The first, most direct and most easily quantifiable, are the input factors—primarily the human and financial resources available to the science and technology enterprise. Trends associated with those resources and their implications are treated in the next section of this chapter—Section B—under the heading, "Maintenance and Development of the Science and Technology Base."

The second, more qualitative, external factors derive from the expectation that science and technology should serve the public good. Effectively, those factors establish priorities. They include rules, regulations, and resource allocation policies and strategies, as well as exhortations, that (1) are intended to focus the capabilities of science and technology on either well-defined problems (such as producing more fuel-efficient vehicles) or broad social goals (such as more equitable health care among all segments of the population), or (2) are designed to mitigate or eliminate present and future risks associated with products and processes made possible by science and technology. The likely effects of some of those factors on research and development during the next 5 years are mentioned in Section B. Those factors also underlie a good deal of the material in Chapter II, which focuses on the likely relationships, during the next 5 years, of science and technology to broad areas of national and international concern.

The third set of factors also derives from the expectation that science and technology can make significant contributions to society. They are not related, however, to specific products and processes, but rather to linkages between science and technology and other types of activity. As such, recognition of their importance as external determinants of advances in science and technology is of relatively recent origin. Although scientific progress is acknowledged to be an indispensable condition for technological development and, by derivation, for social benefit, there is increasing recognition that those linkages are not automatic and cannot be taken for granted. For that reason there is a new concern with forging more effective links between research, industrial innovation, productivity, and economic growth. Such trends are discussed in Section C of this Chapter.

Although they are almost truisms that science knows no international boundaries and that technology is a key to economic development, the implications of those statements—and the qualifications that surround them—have become much clearer in the last two decades as some nations have made use of science and technology to challenge the preeminence of the United States, while others have failed to grasp their promise. Important international issues likely to affect both the U.S. science and technology enterprise and the United States itself are highlighted in Section D.

Finally, science and technology have become such pervasive factors in industrialized societies that scientific and technical information is now widely regarded as a valuable resource for decisionmaking and policymaking in both the public and the private sectors. Nowhere is this more evident than in the assessment and management of risks to people or to the natural environment—the ultimate support for people. Trends in that area are treated in Section E.

B. Maintenance and Development of the Science and Technology Base*

Since World War II, the United States has been a world leader in science and technology. American research and development programs, supported and conducted in the public and private sectors, have maintained our world leadership position in basic research, have provided the educated people needed to define and attain national objectives in science and technology, and have provided technological innovations needed to improve industrial productivity and economic growth and to maintain our national security. Over the past decade, American citizens have won 57 Nobel Prizes in science and medicine, compared with 28 abroad. Additionally, Americans continue to publish a major portion of the scientific papers in a wide range of fields (NRC–Obs.; NRC–13).

However, America's international preeminence in both science and technology is being challenged. Part of the loss of our undisputed dominance in virtually all fields of science and technology derives from the restoration of the productive and intellectual capacities of Western Europe and Japan that were destroyed during World War II. Additionally, recent studies suggest that, although the Nation's scientific research system currently is strong, a range of significant emerging problems could pose a threat to its long-term vitality. Major stresses that appear to be developing include (1) fiscal and personnel resource constraints; (2) increasing costs of instrumentation for advanced research activity; (3) growth of pressures for short-term returns on research investments; and (4) demographic changes affecting the conduct of research carried

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*Abbreviations in parentheses appearing throughout the text refer to more complete discussions in the companion *Source Volumes*. A key to those abbreviations is given at the end of the Preface. Citations to the published literature are designated by footnotes out in colleges and universities (NRC–13). Each of those factors is discussed in detail later in this section.

Signs of stress are even more apparent in the technological sphere. The United States currently maintains its leadership position in several high-technology fields, including aviation, microelectronics, computers, and advanced materials technologies. However, there are other areas—automotive design, consumer electronics, steelmaking, ship construction, rail transportation, and, significantly, scientific instrumentation—where the once dominant position of the United States has eroded. While the United States continues to maintain its leadership in most basic technologies critical to national defense, the Soviet Union is closing the gap in such key areas as electro-optical sensors, guidance and navigation, hydroacoustic technology, optics, and propulsion (NS).

There is no general consensus about the causes of the erosion of our international technological position. Few believe it is a result of a decrease in the inherent capacity of U.S. scientists and engineers to innovate. Rather, there appears to be a notable failure to implement innovations once they have been developed. Many of the most dramatic technological developments abroad are actually based on American developments that we simply failed to commercialize or otherwise implement. Most industrial observers believe that the technological lag in many U.S. industries is not attributable solely or even primarily to weaknesses in the research and development (R&D) system. They argue that many contributing factors are external to industrial control. The problem of industrial innovation and its relationship to scientific and technological activities is discussed in more detail in the next section of this chapter.

In short, although the American science and technology enterprise is generally healthy, several problems that are appearing on the horizon could result in serious erosion of that enterprise. This section highlights trends likely to have important effects in the near future on the capacity of the United States to maintain its international leadership in scientific research and take advantage of the social and economic potential provided by its scientific and technological resources. The focus in this section is on the major elements of the science and technology base: the financial resources needed to sustain its activities, its personnel resources, and its institutions and facilities.

FINANCIAL SUPPORT FOR SCIENCE AND TECHNOLOGY

The financial resources available for science and technology programs are, obviously, a critical element determining the vitality of the U.S. science and technology enterprise. Policy questions associated with the allocation of financial resources include these: At what levels should different science and technology programs be supported? Toward what ends? How should responsibility for support be divided between the public and private sectors?

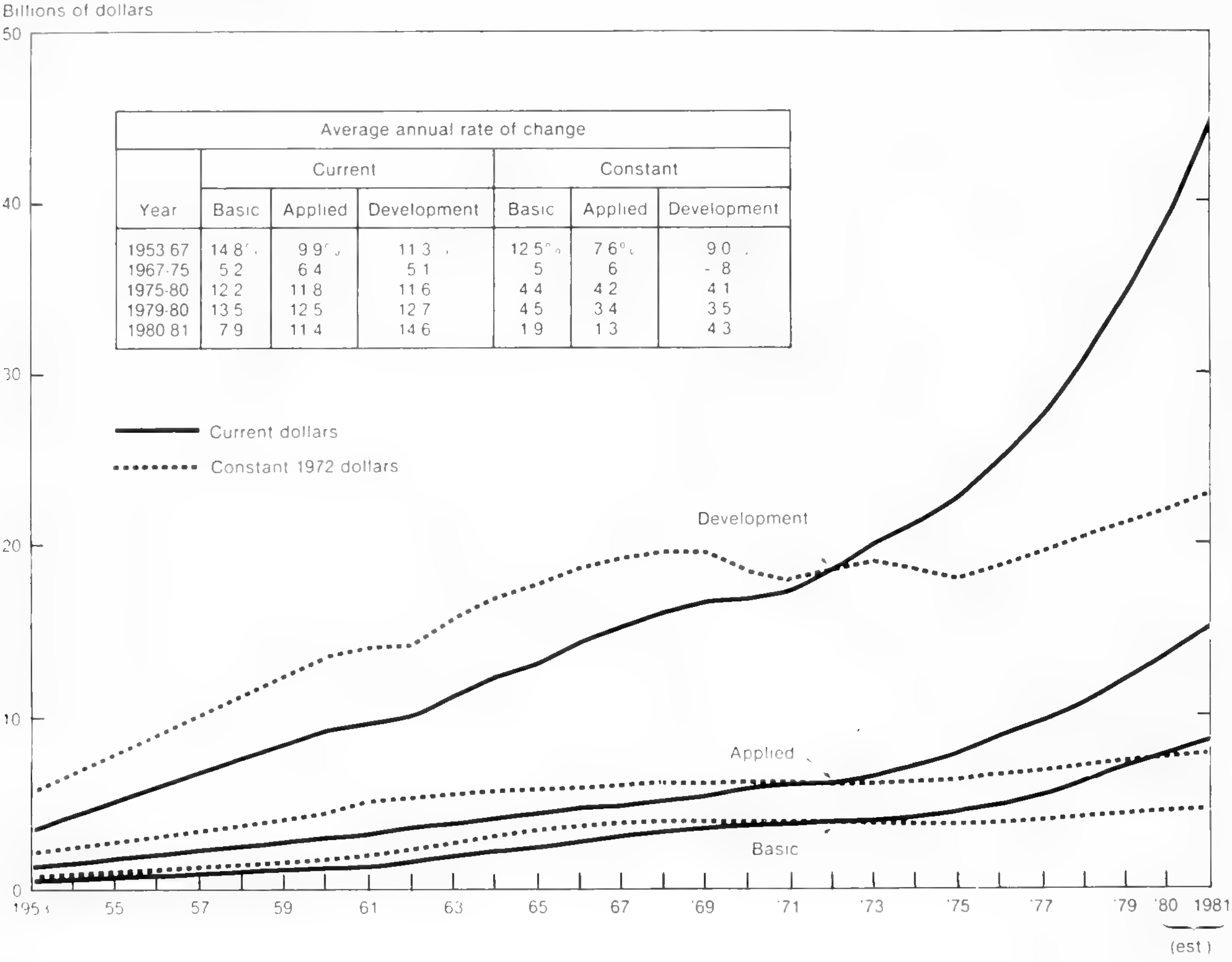
Figure 1 shows trends in U.S. R&D expenditures in both current and constant dollars. During 1981, total national expenditures for all R&D activities were estimated to be $69.1 billion, with the Federal Government's share estimated at 47 percent and private industry's share 49 percent. National expenditures for basic research during 1981 were estimated to be $8.8 billion, with the Federal and industrial shares estimated to be 68 percent and 16 percent, respectively (*SI–80*).

It is interesting to compare U.S. R&D expenditures with those of some other major industrialized democracies.[1] In doing so, two points are noteworthy:

(1) The United States invests more in R&D than France, West Germany, and Japan combined. Although the percentage of Gross National Product (GNP) committed to total national R&D investments in the United States peaked in 1964 and generally declined through the early to mid-1970s, it is still higher than in most other countries except the Soviet Union and West Germany (Figure 2). That percentage has also declined or leveled off since 1967 in the United Kingdom and France, while it has risen appreciably in West Germany and Japan. Whether economic conditions will permit those countries to increase or even maintain their investments is a subject of considerable interest abroad, as noted in Section I-D. In most cases—including the United States—changes in the percentage of GNP committed to R&D since about 1975 have been fairly small.

(2) The U.S. *civilian* R&D/GNP ratio continued to increase through 1970 and, after a temporary decline in the early 1970s, rose to a percentage level of 1.6 in 1979. However, the percentage is still considerably below that of West Germany and Japan.

Considering, second, the Soviet Union, available evidence indicates that the percentage of Gross National Product committed to R&D rose above that of the United States in 1967 and now is the largest in the world. Although the percentage dropped slightly since 1975, it was estimated to be 3.5 in 1978, compared with 2.2 in the United States, 2.4 in West Germany, and 1.9 in Japan. Since U.S. GNP is approximately twice that of the Soviet Union, the United States still invests more in R&D than the Soviet Union in absolute terms. In addition, the quality of Soviet R&D activities is not always believed to be equal to that of American R&D. Details on the exact proportion of Soviet R&D investments devoted to military and space applications as compared to that in the United States are not available. It is clear, however, that a much higher percentage of Soviet R&D is devoted to military



	Average annual rate of change					
	Current			Constant		
Year	Basic	Applied	Development	Basic	Applied	Development
1953-67	14.8%	9.9%	11.3%	12.5%	7.6%	9.0%
1967-75	5.2	6.4	5.1	.5	.6	-.8
1975-80	12.2	11.8	11.6	4.4	4.2	4.1
1979-80	13.5	12.5	12.7	4.5	3.4	3.5
1980-81	7.9	11.4	14.6	1.9	1.3	4.3

FIGURE 1. National R&D Spending by Character of Work.
[1]Based on GNP implicit price deflator.

Source: National Science Foundation. *National Patterns of Science and Technology Resources*, 1981.

programs. The Soviets have almost surely been outspending the United States in military R&D in recent years (NS).

In summary, the financial resources available for the conduct of R&D remain considerably greater in the United States than in any of the leading industrialized democracies. However, several of those countries have been closing the gap in total R&D investments as a fraction of GNP. The Soviet Union spends a larger percentage of its GNP on R&D than does the United States, and has been closing the gap in total R&D expenditures.

RESPONSIBILITIES AND RATIONALES FOR SUPPORT

International comparisons are interesting and often useful. However, since reporting bases differ among countries and inflation rates vary, the comparisons cannot be taken too literally (NRC–13). Importantly, such comparisons cannot address directly, or provide answers to, the question of whether U.S. support for science and technology is adequate to meet the Nation's long-term needs.

Both the public and the private sectors have responsibilities for supporting science and technology in the United States, but their missions and roles differ. Their proportional contributions vary considerably among the industrialized democracies. In the United States, approximately half the investments in R&D come from the Federal Government, and, of those, well over half are allocated for national security and space. The United Kingdom and France show similar investment patterns. That is, the government provides more than half the R&D funds, and a major share of those funds is focused on national security.

In contrast, private industry provides the largest share of support for R&D in West Germany and Japan. In both countries, funds are more highly concentrated in areas

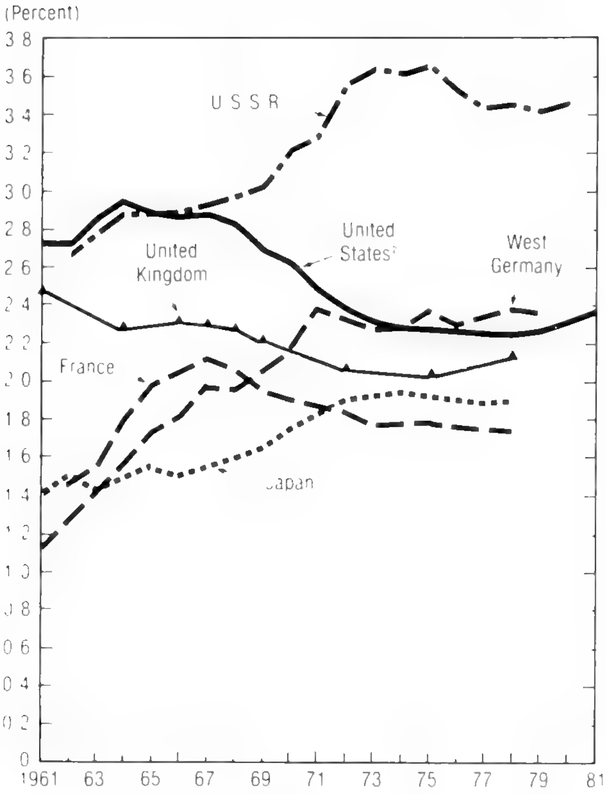


FIGURE 2. National Expenditures for Performance of R&D[1] as a Percent of Gross National Product (GNP) by Country.

[1] Gross expenditures for performance of R&D including associated capital expenditures, except for the United States where total capital expenditure data are not available.

[2] Detailed information on capital expenditures for research and development are not available for the United States. Estimates for the period 1972–80 show that their inclusion would have an impact of less than one-tenth of one percent for each year.

Note: The latest data may be preliminary or estimated.

Source: National Science Foundation. *Science Indicators*, 1980.

directly related to economic growth (for example, manufacturing, transportation, and telecommunications) than in the United States. Governments of the United Kingdom, France, West Germany, and Japan also allocate a higher proportion of their total funds for support of research in universities and national laboratories than does the United States. That is most markedly the case in West Germany and Japan (*SI–80*).

In the United States, private industry engages in and supports R&D primarily to produce or improve marketable, profitable products and processes or, increasingly during the 1970s, to meet environmental, safety, and health regulations. American industry also provides some support for university research and teaching, but that support is small relative to the expenditures it makes to support its own R&D.

The rationale for Federal support of R&D in the United States, both in its own laboratories and in other institutions, is varied. Since World War II, the Federal Government has assumed responsibility for supporting science and technology to fulfill three broad objectives:

(1) to support its own direct responsibilities (in such areas as national defense, space, and air traffic control);
(2) to accelerate the rate of technological development in the private sector in areas of overriding national need, particularly when financial risks are large and the costs are inordinately high relative to potential short-term returns on investments (in such areas as agriculture, health, energy, and transportation); and
(3) to support the research needed to maintain, develop, and replenish the store of knowledge, tools, personnel, and skills that underlie and provide the base for the U.S. science and technology enterprise.

Research and development activities in all three categories are carried out both in the Federal Government's own laboratories and in other settings. In the latter, performers are supported by either contracts or grants.

Since the Federal Government is the primary, if not the sole, consumer of the results of the first type of activity, levels of support can be related directly to its own specific end-use requirements. For example, a high priority of the Administration is to rebuild the Nation's defense capabilities. Thus, the President's fiscal year 1981 and 1982 budgets proposed appreciable increases in defense-related R&D in order to narrow the aggregate gap between U.S. and Soviet expenditures in that category (NS).

Among the three categories of Federal R&D support, the most intense policy debates during the next 5 years are likely to surround the second. Not only is there no consensus about how to determine which areas of national need are sufficiently important to justify Federal developmental support of the private sector, but there is disagreement about appropriate levels of support, distribution of effort between Federal laboratories and private industry, and whether Federal support should come directly as a contract, subsidy, or low interest loan, or indirectly through such means as tax incentives and procurements. The Reagan Administration will no longer support programs of an economic subsidy nature. For this reason, the President's budgets have proposed significant reductions in many R&D programs that appear to have near-term commercial payoffs.

CRITERIA FOR FEDERAL SUPPORT OF BASIC SCIENCE AND ENGINEERING

Issues associated with resource allocations in the third category—often called the basic research category—require somewhat more discussion, since that category, of the three, is most directly linked to maintaining and developing the U.S. science and technology base.

The assertion that the Federal Government has a responsibility to invest in developing and maintaining the knowledge base was the most novel and far reaching feature of Vannevar Bush's 1945 classic, *Science—The Endless Frontier.*[2] Despite the urgent need for fiscal restraint, the President's March 1981 budget proposals included provisions for continued growth in real dollars in Federal support for basic research. Since research of that type most often cannot be justified in terms of foreseeable applications—the benefits to be derived from enhancing the knowledge base often are not immediately derived or even obvious—support levels cannot be determined by quantitative criteria such as returns on investments. Rather, the Federal Government supports research in that category on the grounds that the costs for carrying out such research, particularly on the cutting edges in most fields, are greater than can be borne by the research institutions (frequently universities) and that there is a national need to maintain and promote the development of the knowledge base. Currently, 66 percent of Federal support for basic research goes to universities, including university-administered Federally Funded Research and Development Centers (FFRDCs); 20 percent to national laboratories; 8 percent to other nonprofit institutions; and 6 percent to private industry (*SI–80.*).

Although there is a general consensus about both the legitimacy and the desirability of Federal investments to maintain and replenish the knowledge base, debates are likely to continue about how to delineate research activities in this category from research activities that are meant to underlie the development of a marketable product, and, therefore, are the responsibility of the private sector. Many attempts have been made to identify a unique set of categories to classify all types of research in science and engineering.[3] The basic research/applied research categories are the most familiar, although such other distinctions as long-term/short-term or directed/nondirected are also employed. Recognition is growing that while distinctions such as those are useful for some purposes, it is probably not possible to define a unique set of categories to classify all types of research activity that would be useful for every purpose for which some categorization might be needed. Indeed, overemphasizing the basic research/applied research classifications may suggest that those activities are in some ways antithetical, and thus obscure the essential fact that research spans a broad continuum. But, there is broad agreement that there exists a type of activity characterized by its focus on the development of knowledge, tools, and skills; by the generalizability of its results; and by uncertainty in the length of time likely to elapse before those results are translated into tangible technological developments. That type of activity is referred to as basic research or as basic science and engineering throughout this report.

Basic research is performed in all scientific and, it should be emphasized, all engineering disciplines as well. Indeed, one interesting trend over the past 3 or 4 years is a growing appreciation on the part of scientists that a great deal of research in engineering is, by virtue of its focus on knowledge, tools, and skills, and by virtue of the broad generalizability of its results, fully as fundamental or basic as what has traditionally been regarded as basic research in the mathematical, physical, and biological sciences.

Since research in science and engineering spans a broad range of activities, it is almost never possible to draw a precise line between investments intended to maintain and replenish the knowledge base and those aimed at solving immediate and identifiable problems. In an increasing number of areas, each may feed into the other. Research narrowly aimed at a specific technological development may turn up basic questions worth pursuing for their intrinsic conceptual importance apart from applications. At the same time, basic research may open up technological opportunities that convert a seemingly exotic intellectual puzzle into a challenging development project.

Moreover, research undertaken to improve and refine understanding in one particular area often has dramatic consequences elsewhere. For example, while the original motivation for studying recombinant DNA and other cell fusion techniques was a better understanding of the nature of genetic replication and protein synthetic processes, the findings from those research activities have spawned not only new technologies but whole new industries as well (AAAS–4; HEALTH).

Lasers were originally developed as tools for basic research in physics. However, laser technology has dramatically broadened the capabilities for research in chemistry, and biology as well, and is of great importance in national defense and communications. Lasers are also being used increasingly for military, medical, and industrial applications (NS; GST; *ASTR–III*).

Fundamental research also underlies the development of a wide range of engineering capabilities. The phenomenon of turbulent flow, for example, is associated with bodies moving through a viscous medium, as well as with fluids moving through pipes, pumps, turbines, and heat exchangers. Designers of a broad range of equipment want to ensure a smooth flow because once the flow separates from hulls, airfoils, or ducts, drag or resistance rises abruptly, and the efficiency of the system decays sharply. Recent research suggests that the onset of turbulence may actually exhibit a pulsating structure or repetitive pattern and that it may prove more tractable to mathematical analysis than anyone had thought. If this can be verified, it will have a great impact on all sorts of problems—not simply in the design of aircraft and ships, but in the design of efficient mixing and heat exchange systems like rocket engine combustors and steam condensers.

These examples suggest the difficulty in making support allocation decisions on the basis of the eventual utility of research results. A somewhat different type of suggested criterion for allocating research support among different kinds of scientific and technological activities emerged during the 1970s. According to this criterion, research support should be directed not just to the solution of specific short-term problems or to increasing the knowledge base, but, more broadly, to the attainment of long-term social goals. It has, for example, been suggested that more research in biomedical fields should be directed toward the health care needs of underserved and disadvantaged populations both in this country and abroad (Section II-D). Application of this type of criterion encounters the same problems that arise in trying to target research to specific developmental ends. In addition, it encounters the formidable obstacle of trying to link research and development, which may themselves be carried out in different institutions, with an external social and economic delivery system (in the example cited, the health care system) that is driven by a very different set of imperatives than the research system. The important point, again, is that basic research, by its very nature, is not goal-specific; its utility or potential applications usually cannot be predicted. What may be needed is a mechanism by which recognition of the practical implications of basic research advances can be facilitated as those advances occur.

The desirability of applying a final, related, and largely negative criterion to the determination of research directions was also debated during the 1970s. Application of this criterion would place limits on research whose results could conceivably lead to consequences that might entail risks to individuals and society. The most celebrated instance of research in that category is recombinant DNA research (AAAS–4). The heart of the recombinant DNA debate was not whether scientists and engineers should be exempt from regulations affecting the use of substances known to be or to have a good chance of being hazardous, though there were debates about how such regulations ought to be drawn up. Rather, the central issue was whether the search for knowledge can or should be regulated on the grounds that knowledge *itself* could ultimately prove to be dangerous.[4]

The extension of Federal regulatory authority in the health, safety, and environmental areas during the 1970s—as well as proposals for even greater extensions of its authority—may have derived in part from the erosion of public confidence in the inevitable good to be derived from science and technology that began to become evident in some quarters in the late 1960s (AAAS–1), partly as a result of the rising public sensitivity to environmental damage that could emerge from the application of modern technology. By now, there is agreement that at least some types of regulations are counterproductive. However, there is less agreement on what those counterproductive regulations are and how they should be enforced, or on how to achieve their desired, beneficial effects without doing serious damage to the science and technology enterprise itself (See also Sections C and E). That set of issues will need continued consideration to provide for an appropriate balance between minimizing risk and ensuring the continued development of the scientific and technological base.

HUMAN RESOURCES FOR SCIENCE AND TECHNOLOGY

It is a truism that maximum effectiveness of the science and technology enterprise requires that it be carried out by the best and most highly trained individuals our society can produce. That requires, at a minimum, that adequate numbers of qualified young people be given the best possible education in science and engineering, and that adequate resources are available to permit them to make use of their talent and training.

Universities, the armed services, and, in certain critical fields, industry are reporting severe difficulties in recruiting sufficient numbers of qualified engineers and scientists. Personnel shortages are most acute in computer sciences, in the fields of chemical, electrical, and industrial engineering, and, among scientific subspecialties, in solid-state physics, optics, analytical chemistry, and toxicology.[5] Additionally, medical schools report increasing numbers of vacancies in faculty research and teaching positions (Section II-D).

The Bureau of Labor Statistics has projected a 40 percent increase in employment opportunities in science and engineering occupations at all degree levels from 1978 to 1990.[6] If present undergraduate enrollment trends persist throughout the decade, there should continue to be more than enough new graduates at both the bachelors and Ph.D. levels in all of the traditional fields of science, although unanticipated shortages in specific subfields may develop. In contrast, there almost certainly will *not* be sufficient numbers of people trained in computer science in 1990, although those deficiencies can be alleviated by people trained in related disciplines. The situation for engineering personnel is more problematic. University engineering departments are facing severe problems, discussed below, due to faculty shortages and equipment obsolescence. Thus, it cannot be taken for granted that engineering enrollments can, in fact, continue to expand at a sufficient rate to satisfy anticipated demands.

The anticipated supply/demand situation for Ph.D.-level engineers is even less certain. Given reasonable assumptions regarding inflation and productivity growth rates, there should be adequate numbers of advanced degree engineers by the end of the decade—*provided* that such engineers are not used any differently in the future than they are being used at present. It is precisely at this point that the utility of quantitative personnel projections in providing adequate assessments of the future can be questioned. For although the total supply of Ph.D. engineers—or for that matter bachelors-level engineers—may be approximately equal to demand, small deficiencies in the number of highly gifted and highly trained people in specific, critical subspecialties may seriously hamper efforts to pursue some advanced R&D. In other words, the *quality* of available science and engineering personnel can be, in many important instances, more important than their quantity.

Personnel shortages in scientific and technological fields are not unique to the United States. There also are impending shortages of science and engineering personnel in other industrialized countries (NRC–13). Although the number of scientists and engineers engaged in R&D as a fraction of the labor force is higher in the United States than in the United Kingdom, France, West Germany, or Japan, this fraction has been decreasing in the United States from the late 1960s through the early 1970s, while it has risen in those other countries and, in West Germany and Japan, is continuing to rise (Figure 3). The U.S. fraction has increased slightly in the past few years but has not reached its former level (*SI–80*). The Soviet Union has a substantially larger proportion of its labor force engaged in R&D activities than does the United States, although quality comparisons might yield different results. In 1979, there were between 84 and 95 scientists and engineers per 10,000 members of the Soviet labor force engaged in R&D, and the number appears to be increasing. The comparable figure for the United States in 1979 was 59 per 10,000, and that ratio appears to have stabilized (*SI–80*).

These comparisons suggest that although several countries that are challenging America's international preeminence in science and technology are not without personnel problems, those problems are potentially more severe in the United States. Therefore, both qualitative and quantitative aspects of the science and engineering personnel situation in the United States will continue to require attention in the coming years.

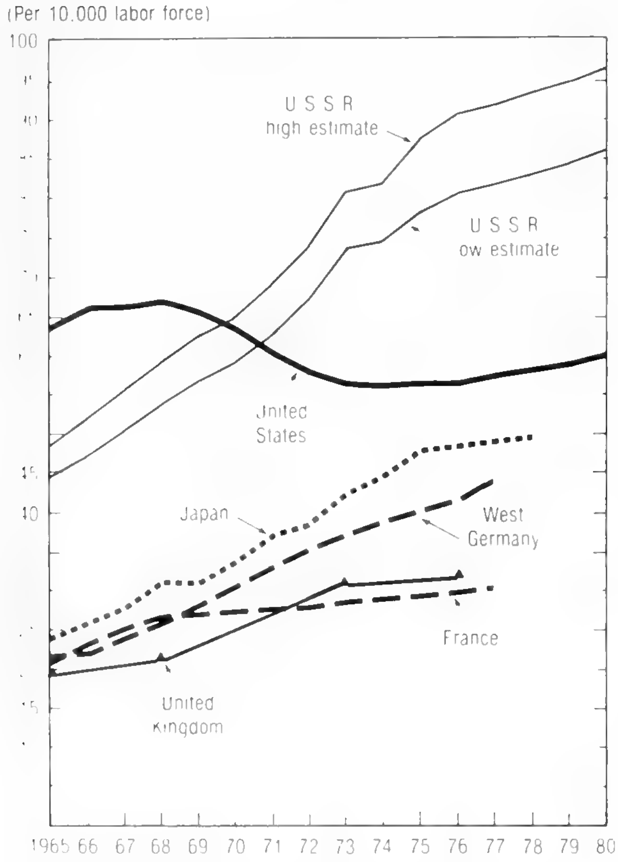


FIGURE 3. Scientists and Engineers[1] Engaged in R&D per 10,000 Labor Force Population by Country

[1] Includes all scientists and engineers on a full-time equivalent basis (except for Japan, whose data include persons primarily employed in R&D, and the United Kingdom, whose data include only the Government and industry sectors).

Note: A range has been provided for the U.S.S.R. because of the difficulties inherent in comparing Soviet scientific personnel data.

Source: National Science Foundation. *Science Indicators*, 1980.

RESEARCH INSTITUTIONS

Approximately 70 percent of American total R&D (on the basis of funds expended) is performed by private industry, 13 percent is carried out in government laboratories, about 10 percent in universities and colleges, 4 percent in university-administered federally funded research and development centers, and the remainder in other nonprofit laboratories[7] (Figure 4). Most scientific and technological activities of industry are classified as development work. Approximately one third of U.S. national R&D expenditures is directed toward basic and applied research programs, and approximately 50 percent of all basic research is conducted in university settings.[8]

Financial resources and, in some critical cases, personnel resources for scientific research in the civilian sector are likely to remain tight during the next 5 years, although the President's economic policy is designed to encourage increased investments by private industry. In view of those constraints, there is likely to be increased emphasis on justifying proposed research directions in all types of institutions and on evaluating their results. There probably will also be continuing pressures toward structural changes that might facilitate research. During the recent past, there has been renewed interest in forging closer links between university and industrial laboratories. Implications of that trend, which is likely to accelerate during the next 5 years, are discussed in the next section of this chapter.

UNIVERSITY RESEARCH

The Nation's higher education system has been at the leading edge of the extraordinary growth and superb quality of the research that gave the United States preemi-

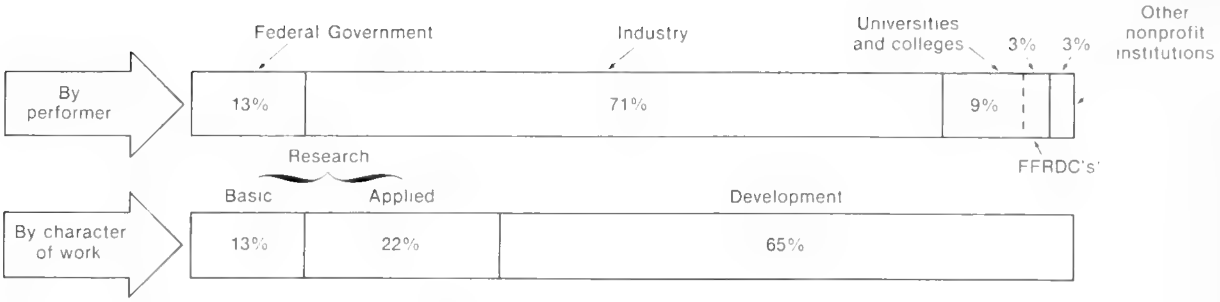


FIGURE 4. The National R&D Effort [expenditures for R&D = 69.1 billion, 1981 (est.)]

[1]Federally funded research and development centers administered by universities and colleges.

Source: National Science Foundation. *National Patterns of Science and Technology Resources*, 1981.

nence in science and technology during World War II and in the succeeding decades. That growth was due in large measure to the infusion of Federal support for scientific research. In recognition of the unique contributions made by university laboratories, the President's March 1981 budget proposed an increase of 6.1 percent in university R&D support between fiscal years 1981 and 1982.

During the past decade, American universities, including their science and engineering departments, have been subject to unusual pressures resulting from demographic changes and continuing high rates of inflation. Those pressures have strained their effectiveness both as teaching and as research institutions. Since the size of the 18-to-24-year-old age group will continue to decrease until well into the 1990s, competition for undergraduates among American colleges and universities is likely to become even more severe during the next 5 years and beyond.[9] While university research in science and engineering is supported heavily by funds from external sources, financial problems experienced by a university as a whole have direct effects on its science and engineering capabilities. For example, most university research is conducted by teaching faculty who receive at least a portion of their salaries from general university funds. Thus, the size of university science and engineering departments and the amount of research they can conduct are strongly dependent on student enrollments and on the general health of the universities.

University science and engineering departments are currently experiencing two major problems that limit their effectiveness in both teaching and research: faculty recruitment and retention, and equipment obsolescence. Faculty problems are almost diametrically different in science and engineering departments; the dimensions of the equipment problem are very similar.

In most science departments, the major faculty problem is one of limited opportunities for younger scientists. Because of financial stringencies, decreasing enrollments, and the fact that an appreciable fraction of the tenured faculty is well below retirement age, science departments have fewer openings for new Ph.D. scientists than they did a decade ago. This situation is particularly apparent in mathematics and physics. Since young scientists are often among the most creative and productive, their decreased presence raises serious problems for the health of the universities and the scientific enterprise in general (NRC–13; *ASTR-III*).

In contrast, engineering and computer science departments are experiencing faculty shortages at all levels, and little relief is in sight during the next 5 years. Undergraduate enrollments in those fields have been increasing for the past 5 years, while the number of Ph.D.'s awarded has been declining for almost a decade.[10] Thus, the total pool from which new doctoral-level engineers can be drawn to staff a research faculty has been decreasing, while, at the same time, competition from industry has been increasing. Not only can industry offer Ph.D. engineers better salaries than universities can, but, importantly, research facilities available in industry have become decidedly superior to those in universities, a situation that has grown worse during the past decade with the improvement of industrial laboratories and some deterioration of university engineering laboratories. Imbalances between aggregate supply and demand for engineers in industry may well be resolved by free market mechanisms. On the other hand, problems faced by engineering and computer science departments in universities have resulted in large measure from their failure to compete for qualified personnel. Current steps being taken by the Federal Government to ease the severity of the problems include provision of research assistantships as a component of grants and contracts to engineering departments for graduate students who are interested in, and qualified for, academic careers. Increased cooperation between universities and industry to facilitate joint appointments and cooperative exchange programs would be an additional, useful component of any long-term solution to faculty personnel problems.[11]

Equipment obsolescence is a second severe problem for university science and engineering laboratories. During the 1970s, such equipment-intensive fields as physics, chemistry, the life sciences, computer science, and engineering experienced rapidly escalating costs for maintaining existing laboratory facilities and for developing and purchasing the newer, more sophisticated state-of-the-art apparatus needed to conduct research at the cutting edge of those fields. According to one estimate, equipment replacement costs rose at an average rate of 4 percent above inflation during the 1970s. At the same time, Federal funds for research equipment and facilities declined sharply during that period, and few universities have been able to provide sufficient assistance for equipment purchase or facilities modernization from their general funds to offset the decline in Federal support.[12]

The equipment obsolescence problem, which has already been cited as one factor contributing to current shortages of engineering faculty members, is having a direct effect on the quality of university research conducted in equipment-intensive fields in both science and engineering. The problem could also have adverse consequences for industrial research laboratories that have, in the past, relied heavily on university laboratories for innovative instrumentation concepts. In the words of one observer, the "dynamics of the concurrent advances in scientific instrumentation and industrial technology lie at the heart of the American success story in both areas."[13]

There are several conceivable remedies to the instrumentation problem. They include, in addition to closer university-industry cooperation, special research equipment purchase grants, greater flexibility in Federal research grant and contract management procedures that would encourage pooling of equipment funds and sharing of apparatus among university departments, expansion of regional instrumentation facilities, and expansion of centralized research facilities for university users at federally supported national laboratories.

Several scientific disciplines, including oceanography, radio astronomy, and high-energy physics, have long since adapted to using such centralized facilities. The centralized arrangements have enabled substantial research progress in those fields, and some observers believe that their extension to other scientific fields is both inevitable and desirable.[14] Considerably greater use is made of centralized research facilities outside the university system in Western Europe than in the United States. Basic research is conducted both in universities and in associated organizations that are not integral parts of universities both here and in Europe. But, whereas in the United States those associated organizations—the national laboratories—are administered by universities or consortia of universities, in Western Europe—particularly France and Germany—systems of government-supported laboratories exist independently of, and in parallel with, the universities. For that reason, the number of available research positions (and the capacity of those countries to conduct research) is less closely tied to student demographics than in the United States (NRC–13).

Additionally, France, Germany, and the United Kingdom all maintain a dual system for supporting research. First, continuing institutional support for conducting research is provided to both university and nonuniversity laboratories. Second, grants for special research projects are provided, as in the United States. The three countries also provide support for longer periods of time and for more aggregated research efforts than does the United States. Finally, because of their more limited resources, the Europeans rely more extensively than the United States on cooperative programs at various levels—within individual laboratories, regionally within their own countries, and internationally with one another (NRC–13).

Given the increasing scale, cost, and complexity of basic research, the European experience, particularly with cooperative research arrangements across the entire range of scientific disciplines, is likely to be of increasing interest in the United States during the next 5 years. However, the probable effects of greater centralization of the U.S. research effort on both the teaching and the research functions of universities have yet to be assessed adequately.

RESEARCH IN INDUSTRY

Industry-based scientific research laboratories date from the late 19th century, stimulated in large measure by the success of German industry in coupling scientific results to industrial development, particularly in the synthetic dye industry. Practices in early industrial research laboratories, which emphasized an interdisciplinary, scientific approach to problem solving, were in many ways counter to the more prevalent model of technology exemplified by Thomas Edison, which emphasized the solution of immediate problems by intuition and ingenuity. Those contrasting styles are still evident in U.S. industrial practice.

The amount and character of the research conducted in private corporate laboratories today differ considerably among industries and with the size of firms within particular industries (Figure 5). However, in spite of those differences, research in industry shares one characteristic that distinguishes it from research conducted in universities and organizations associated with universities: most of it is purposeful; it either aims at the production of a marketable product or aims to respond to Federal regulations (NRC–14). That need not imply that all industrial research is focused on specific, identifiable, short-term objectives; indeed, a good deal is devoted to developing the knowledge and tools needed to maintain long-term industrial vitality. Moreover, the length of time that elapses between obtaining research results and incorporating them into marketable products may be considerable. Viewed from those perspectives, much of the research

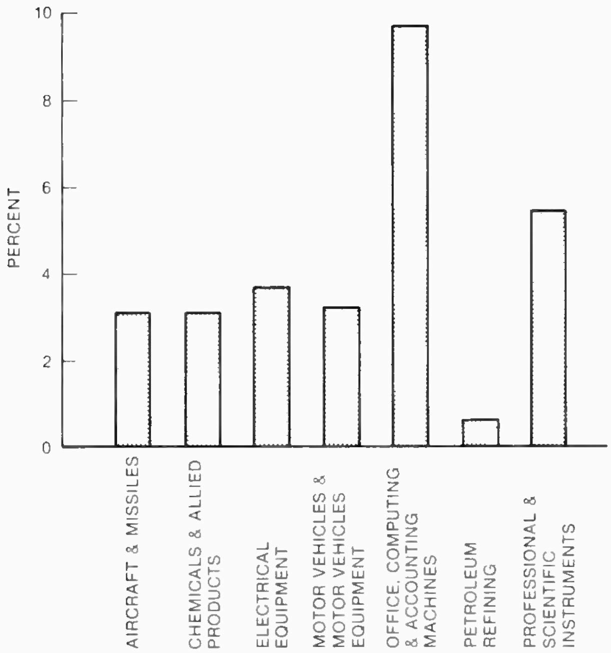


FIGURE 5. Company R&D Funds as a Percent of Net Sales: 1979.

Source: National Science Foundation, Division of Science Resources Studies.

carried out in private industry is as "basic" as the research typically conducted in universities. Nevertheless, industrial research is aimed ultimately at producing or improving a marketable product, rather than at a deepened or refined understanding of some aspect of the physical or manmade universe. This industrial objective can and does act as a mechanism for filtering and directing research.

There is a second, essential, distinguishing characteristic of industrial research that is intimately related to the first: industrial research laboratories, unlike university or government laboratories, are part of a system that includes development, engineering, manufacturing, and marketing activities. With the exception of a few industries, such as some aerospace and defense-related industries that sell most of their output to the Federal Government, industrial firms depend for their survival on their competitive positions in the marketplace. Thus, allocations for research laboratories typically are based on the judgment, by corporate management, of the likely long-term market return for research investments (AAAS–2).

Since the mid-1960s, R&D activities in many industries have shifted away from what has traditionally been called basic research toward very specifically defined programs geared more to the solution of short-term problems (NRC–14). Some of the apparent shift away from long-term basic research in industry may be due to problems in distinguishing basic and applied research in industrial settings.[15] However, there is a strong consensus that corporate management has been increasingly concerned with short-term profits at the expense of long-term investments in projects that are high risk and have long payback times (NRC–14; AAAS–2). Edward David has noted that in medium- and large-size firms that can afford centralized research laboratories, there is almost always a struggle between those who believe that research should serve the interests of marketing and production and those who believe that the potential of new technologies ought to have a large influence over marketing goals. That opposition between short-range and long-range perspectives has been inherent in industrial research since the 19th century.[16] But, during the 1970s, as profit margins decreased for many industries and, in some cases, all but vanished, there began a strong trend toward reducing long-term research investments (NRC–14).

There are many who believe that the trend away from long-term investments in research in some industries has been a primary contributor to the erosion of U.S. leadership in some critical industries (NRC–14; AAAS–2). While the President's economic policy is designed to encourage greater private sector investments in R&D, resources for industrial R&D are expected to continue to be somewhat constrained during the 1980s. The amounts available will depend on several factors, including the likelihood that the legal and regulatory climate will not unduly impede the transition from R&D to commercialization. The specific effects of those factors will differ among industries. But overall, there is likely to be increased emphasis on selecting and justifying high-quality research efforts and on placing priorities on the selection of long-range efforts.[17]

Because they are less capital and energy intensive than many other industries, considerable R&D growth is anticipated in the next 5 years in those areas of the electronics industry dealing with microprocessors and minicomputers, data communications equipment, and integrated circuits. Advances in computer capabilities should permit appreciable productivity increases in other manufacturing industries, including the automotive, aircraft, chemical, and pharmaceutical industries. In the capital-intensive automotive and aircraft industries, research aimed at more energy-efficient products that also meet mandated regulatory standards will very probably be emphasized. The possibility of rising energy prices is certain to stimulate research in the energy-producing industries. Research in the chemical industry is likely to focus increasingly on improving process economics, reflecting rising costs for raw materials and energy, rather than on developing new products as in the past. The pharmaceutical industry is expected to benefit from the explosion of fundamental knowledge in biochemistry, molecular cell biology, immunology, and neurobiology. That increased understanding, together with sophisticated research instruments now available, should result in a new era of drug discovery and development—one in which drugs are targeted to interrupt a specific disease process rather than simply treating signs and symptoms. Focused research and development of that nature should help to mitigate the effects of Federal regulations that, by greatly increasing the number and types of tests required before a new drug can be marketed, have led to rapidly escalating costs for research, development, and commercialization (NRC–14).

Devising ways to improve the linkages between the industrial R&D enterprise and other components of the U.S. research system—particularly the universities—is one of the issues associated with industrial R&D activities that is likely to receive prominence during the next 5 years. Another critical issue is the role of the Federal Government in stimulating (or inhibiting) industrial R&D. Those issues are related to the problems of innovation, productivity, and economic growth and are treated in more detail in the next section.

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C. Contributions of Science and Technology to Industrial Innovation, Productivity, and Economic Growth

The President's February 5, 1981, address to the Nation on the economy emphasized the goals of fostering industrial innovation, increasing productivity, and stimulating economic growth to increase the quality of life of all Americans and to maintain our national security.[1] Figure 6, which shows that the overall growth of productivity in manufacturing industries in the United States has lagged behind that of several other industrialized nations, provides ample grounds for the President's concern.

A wide variety of factors influence innovation, productivity, and economic progress, including inflation, energy prices, and labor costs (NRC-Obs.). Research and development activities are, however, of particular relevance to this report since they underlie the innovation process and provide many of the tools needed for increasing productivity.

There is considerable evidence pointing to the historical and current relationship between American science and technology and economic growth. The Committee on Economic Development (CED) has, for example, expressed the view that "technological progress is perhaps the most important source of future economic vitality and social progress for the United States".[2] That perspective is also evident throughout the contributions that appear in the accompanying *Source Volumes*. Studies cited in *Science Indicators–1978* show that, between 1948 and 1969, 34 percent of measurable U.S. economic growth derived from advances in knowledge and that industries with high

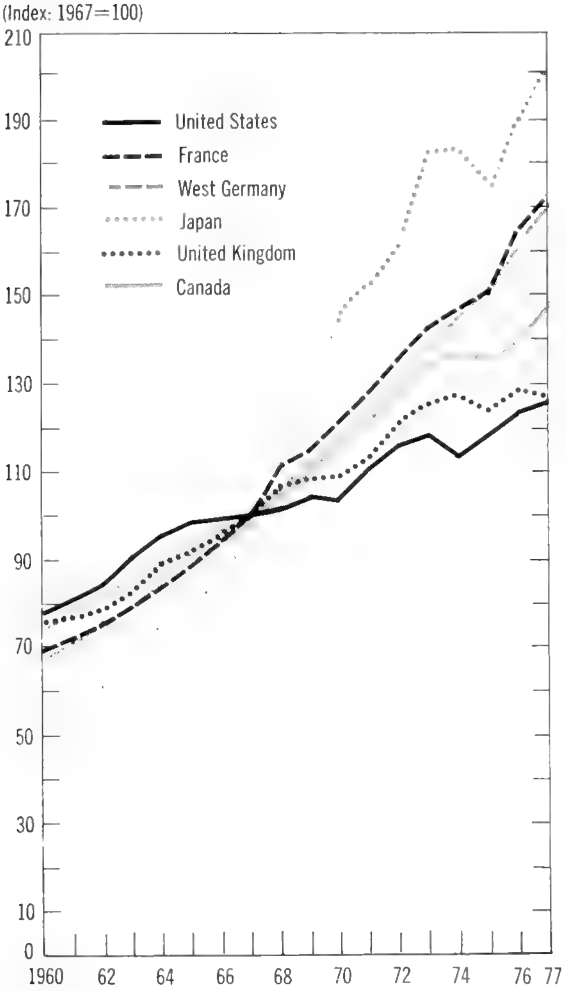

FIGURE 6. Relative Change in Productivity[1] in Manufacturing Industries by Selected Countries: 1960–77.

[1]Output per worker hour.
Note: Estimates are shown for latest year.
Source: National Science Foundation. *Science Indicators*, 1978.

ratios of R&D spending to sales (for example, chemicals, electrical machinery) experience substantially higher growths of productivity and output than industries with low ratios (for example, textiles). Research results reported in *Science Indicators—1980* confirm these implicit correlations and trends. A study by Mansfield suggests that there is a strong and direct relationship between the amount of long-term basic research carried out by a firm and its rate of productivity growth, even when the amount invested in applied R&D is held constant.[3]

Since the persistence of the relationship between advances in knowledge, innovation, and economic growth is not easily documented, those estimates are subject to some uncertainty.[4] For example, productivity is very difficult to quantify; approaches to its measurement depend on interpretations of its meaning, which vary considerably. In a purely quantitative sense, productivity can be viewed as the ratio of outputs, in terms of physical quantities of the product produced, to inputs, such as labor and capital. But, those kinds of estimates do not take into account such things as the quality of the product produced. Therefore, quantitative indices of productivity that are based on the number of items produced and do not show increases in quality over time can give the impression of stagnation in productivity advances. Indeed, the contributions of advances in technology to the qualitative aspects of productivity could be far greater than purely quantitative measures would suggest. Moreover, the problem of stimulating industrial innovation cannot be divorced entirely from the problem of the social utility of a particular innovation.

Despite these caveats, there is wide agreement that there has been and continues to be a strong relationship between research and development activities and economic growth. Therefore, a major question that will need continuing attention during the next 5 years is: How can the United States maximize the contributions of science and technology to the national goals of increasing innovation, productivity, and economic growth?

THE CAUSES OF LAGGING INNOVATION

Stimulating innovation has been and continues to be a major national goal, implying that current levels are below those expected or desirable. In fact, there are indications that innovation and productivity in some American industries are lagging behind those of several other industrialized countries, such as West Germany, France and Japan, and that the United States is thereby losing its international preeminence in such vital industries as consumer electronics, metallurgy, and automotives (NRC–14; AAAS–2; TRANS). In the military sphere, the Soviet Union appears to be closing the gap in implementing such key technologies as electro-optical sensors, guidance and navigation, hydroacoustics, optics, and propulsion (NS).

Understanding the causes of the innovation lag in the United States requires some dissection of the total industrial innovation process. That process consists of a series of stages ranging from the generation of new ideas, through the development of pilot projects to further refine and develop new technologies, to their conversion into marketable products and processes. There does not appear to be any decline in the ability of industrial scientists and engineers to come up with innovative ideas. Rather, most observers believe that the problem is inherent in the subsequent stages of the total innovation sequence—namely in providing sufficient support to the R&D activities needed to convert seminal ideas into marketable products and processes (NRC–Obs; NRC–14). The Japanese consumer electronics industry, for example, owes much of its current success to the successful adaptation of technologies developed in the United States (AAAS–2). Japanese industry also appears to have made good use of organizational behavior data to streamline industrial processes. Additionally, manufacturing processes in such key U.S. industries as metallurgy and automotives do not employ the best available computer-assisted technologies. American industry had, for example, some 2,000 robots at work in assembly line production in 1980, compared with 13,000 in Japan (NS).

It appears that one important reason for the lag in innovation in some industrial sectors is a decrease in the growth rate of industrial investments in long-term R&D programs and in incorporating the results of R&D into manufacturing processes (NRC–14; AAAS–2; *ASTR–II; Outlook I*). Although, in absolute terms, there has been a substantial increase in total industrial R&D outlays over the past few years—compensating somewhat for a marked reduction during the early and mid-1970s[5]—there appears to be a major shift in the form of research and development investments in some American industries. That shift is away from long-range research and development toward a concentration on short-term needs.[6] At least a part of this has been due to the great increase in Government regulations in the 1970s. The shift toward short-term problem solving is likely to continue to have dramatic negative effects on industrial innovation in the future (NRC–14).

When viewed in comparison with other countries, total R&D investments in the industries of most other major industrialized nations have been increasing over the past decade at a faster rate than those of the United States. That difference is apparent both in terms of the amount of money invested in R&D relative to the Gross National Product and in terms of the number of scientists and engineers as a proportion of the total labor force. Moreover, in West Germany and Japan, R&D investments are more heavily concentrated in such areas as manufacturing, transportation, and telecommunications that are directly related to economic growth *(ASTR-I; SI–80)*. Some experts believe that the relative decline in research and development investments in some American industries has had and will continue to have major effects on the international competitive position of many U.S. firms (AAAS–2; AAAS–6).

This background suggests that two kinds of related actions may be needed if the rate of industrial innovation is to be significantly stimulated in the long term. First, an overall increase in industrial investments in R&D; second, redirection of a larger part of those investments toward long-range projects rather than toward short-term problem solving. President Reagan's tax plan is designed to accomplish precisely those goals.

THE REASONS FOR CURRENT PATTERNS OF INDUSTRIAL RESEARCH AND DEVELOPMENT INVESTMENTS

Any suggested mechanisms for changing current patterns of industrial research and development investments as a means for fostering innovation must consider the reasons why current patterns exist. Two kinds of factors typically are cited. One set of factors is largely beyond the control of industry; the other set is inherent in current industrial management practices.

FACTORS EXTERNAL TO INDUSTRY CONTROL

The first set of factors typically cited is largely external to business and industry. It includes such things as energy prices, high inflation rates, Federal tax and patent policies, and Federal regulations. Federal regulations, in particular, can require that industrial resources be directed toward meeting their requirements and away from investment in long-term R&D (NRC-Obs.; NRC–14).

The nature of Federal regulations varies widely, as do their efficacy and the degree to which they discourage long-range R&D investments. In some cases, as in energy-related industries, regulations are concerned with processes. In others, as in the food and drug industries, they are concerned primarily with products. Some regulations have spawned R&D aimed at profitable control technologies. That has been the case in industries—the chemical industry, for example—where regulations typically specify control by the use of the best available means rather than by specifying a level of control without reference to any means to achieve that end (NRC–14). Despite the wide variation in types of regulations, there is a strong perception in industry, and in this Administration, that the effect of the broad extension of Federal regulatory authority during the 1970s has, on balance, been negative.[7] In industries that both are capital intensive and produce a complicated product (such as an automobile or an airplane), changes to meet specified regulatory ends are not easily made. They involve redesign and testing of more than one part and often necessitate major capital expenditures. In many cases the funds for such changes are not readily available, with the result that long-term R&D programs are compromised to obtain them (NRC–14). For somewhat different reasons, regulation of the pharmaceuticals industry has been cited as a particularly notorious example. Those regulations have increased markedly both the cost and the time required to bring a new drug to the market and, thereby, have raised the market prices of new drugs. In addition, regulations have slowed down the flow of new drugs and reduced the number of companies with financial resources adequate to engage in the development of new drugs. Those kinds of negative effects have raised questions about whether regulation of the pharmaceuticals industry has, on balance, been in the public interest (NRC–Obs.).

In addition to imposing the need for such defensive research in industry, Federal regulations add to uncertainties on the part of corporate managers about whether products resulting from investments in R&D can be marketed at competitive costs, or even at all.[8] Although few would suggest that industries should not be regulated at all, there is reasonably strong sentiment that Federal regulatory policies can and should be made more efficient and selective, thereby reducing some of the costs of meeting regulatory requirements and encouraging greater investment in long-term R&D (NRC–14). The President's Task Force on Regulatory Relief, chaired by the Vice President, is expected to make recommendations to improve the rational bases for establishing regulatory priorities.

FACTORS INHERENT IN AMERICAN MANAGEMENT CHARACTERISTICS

Investments in long-term R&D programs clearly depend on the willingness or propensity of industrial managers to make those kinds of investments. However, current management practices, at least in some industries, notably metallurgy and automotives, may bias against making long-term investments (NRC–Obs.). The automotive and aircraft industries have already modified their products both to increase fuel efficiency and to reduce energy used in production. But it is clearly difficult for industries facing severe financial problems to increase their investments in long-term R&D (NRC–14). Moreover, as argued by Abernathy and Rosenbloom (AAAS–2) and by Prewitt (SSRC–1), industrial reward systems for high-level executives can have a negative effect on long-term R&D, since rewards or bonuses to executives frequently are based on short-term profits, which encourages a short time horizon. Long-term investments in new and perhaps risky technologies, as well as costly retooling of existing machinery to accommodate new technical advances, have little immediate payoff, a condition that does not lead to reaping immediate rewards.

It also has been argued that investment in long-term technological development demands a certain basic understanding of the technical base of the industry and that American recruitment and selection practices for high-level managers in some industries often are counterproductive for long-term innovation investments. Managers in those industries are selected for their managerial or business skills and may have little appreciation of the technical base of the company. Therefore, they are less likely to appreciate the need for long-range research and development programs (AAAS–2). In contrast, in other industries where top managers frequently have scientific and engineering backgrounds (such as the information and chemical industries), the rate of technological innovation continues to be reasonably high. The problem of lack of technical expertise among managers is compounded by those high-level executives who move from one business to another fairly often and do not have time to learn about the industry's technical base (AAAS–2). The situation is different in some other industrialized countries, most notably Japan, where business personnel frequently stay with a single company for long periods of time, perhaps for their entire careers, and managers often are sophisticated about the company's technologies and technological capabilities (AAAS–2).

To the extent that these arguments are valid, they suggest that some of the responsibility for lagging innovation in the United States lies with American management culture. Rettig suggests that some of the counterproductive management practices are also increasingly evident among Federal program managers, who are unwilling to invest Federal funds in long-term, potentially risky projects. That provides a challenge to both the private and the public sectors in the coming years to reevaluate and, perhaps, change some of their managerial philosophy (AAAS–1).

SOME REMEDIAL APPROACHES

Having suggested, first, that there is a lag in American industrial innovation and, second, that some of the causes of lagging innovation are related to current patterns of industrial research and development activities and investments, reasonable questions include: What can be done? By whom?

CONTRIBUTIONS OF THE SCIENCE AND TECHNOLOGY ENTERPRISE

Since the total innovation process begins with the generation of ideas, providing additional basic concepts and methods is one way that science and technology might contribute to overcoming the lag in American industrial innovation. However, this is not the stage of the innovation process where the most dramatic problems lie; there does not seem to be a dearth of innovative ideas. Rather, the critical problems seem to lie more heavily in the later stages of the innovation process—in the stages of developing those seminal ideas and converting them into marketable products and processes (NRC–Obs).

In addition to providing increased capacity for innovation through improving the innovation process, science and technology activities can have an impact upon the factors both internal and external to industrial control that presumably are contributing to the current lag in American industrial innovation. If, for example, one cause of the innovation lag is an unwillingness of managers to invest in long-term and potentially risky research and development programs, then American managerial practices may have to be reevaluated. A wide range of disciplines, including those concerned with organizational behavior and with economics, can contribute concepts and methods by which to conduct that reevaluation, as well as suggesting new and more effective approaches to management (SSRC–1).

Furthermore, social science methods can be used to evaluate the impact of factors external to industrial control on the innovation process. Those methods can be used effectively to evaluate such things as the relative costs and benefits of Federal regulations and Federal tax and patent policies, as well as the impacts on innovation of such factors as inflation and energy prices. The findings can then provide a basis for framing appropriate remedial steps (SSRC–1). The more general topic of the use of scientific information in decisionmaking and policymaking is discussed in Section E of this Chapter.

THE GOVERNMENTAL ROLE

There is little that the Federal Government can do directly about the internal factors inhibiting innovation in the industrial enterprise. At most, government can provide or support a forum for further discussion of the problem (AAAS–1; AAAS–2). On the other hand, government can influence those factors that are external to the industrial enterprise and that are within its control. The Federal role in promoting industrial innovation has been a topic of extensive discussion over the past few years and is likely to remain so during the next 5 years.

There is general agreement about three broad factors in the Federal role in industrial innovation: first, the importance of the overall economic climate and future economic outlook in stimulating (or inhibiting) corporate managers in their decisions about allocating resources to innovative efforts; second, the importance of such indirect Federal incentives and disincentives as tax, patent, antitrust, and regulatory policies on corporate decisions; third, the importance of the Federal role in maintaining long-range research and education capabilities in the universities to complement and augment industrial capabilities and to regenerate continually the scientific and technical base on which industrial innovation ultimately rests.

There is, however, considerable disagreement within this broad area of consensus about the appropriate form and extent of the government role. Some significant Federal actions aimed at improving the climate for innovation have recently been taken. The Department of Justice issued, in November 1980, a publication titled, *Antitrust Guide Concerning Research Joint Ventures,* which sets forth the standards it will use to examine the permissibility of collaborative research ventures between businesses. Efforts have also been made to facilitate the transfer of research findings from nonindustrial laboratories into the industrial setting (*ASTR–III*). Many studies suggest the need for changes in Federal tax policies to increase industrial investments in R&D-related plant and equipment,[9] and the Economic Recovery Tax Act, signed by President Reagan in 1981, contains R&D tax credits, accelerated depreciation schedules and other incentives designed explicitly to stimulate those investments. Legislation pending in Congress at the end of 1981 would assign to all private sector organizations (and not just universities and small businesses as at present) the rights to patents developed under Federal R&D funding.

The question of when the Federal Government should subsidize or otherwise intervene in private sector R&D is also likely to be discussed further during the next 5 years. Such a direct Federal role is generally accepted in those cases where government itself is the primary consumer—for example, in space and, most notably, defense-related industries. Indeed, Federal investments in defense-related research and development frequently stimulate activities that are also likely to have high, long-term payoffs in the civilian sector. That is the case in the development of very high speed integrated circuits and research in ultrasmall electronics, artificial intelligence and robotics, and advanced materials technologies (NS).

Existing Federal programs that provide modest grants to small firms to stimulate innovative research are also given high marks by many industrial scientists, particularly since they allow considerable latitude in integrating research, development, and marketing strategies. Likewise, a modest Federal role in catalyzing university-industry collaborations may be desirable, even though a good many such collaborations are proceeding without Federal support.[10]

There are doubts about the appropriateness of Federal economic subsidies to stimulate specific commercial developments in the civilian sector, and the Reagan Administration's policy is that, in general, such direct subsidies will not be provided, except in the case of long-term, high-risk but high-potential programs in the national interest that industry is unable to support. Industry alone has sufficient experience to relate R&D to marketing strategies. Since focused Federal R&D support is almost always separated from the market, it is an ineffective device for stimulating specific, near-term commercial innovations that can compete in the market without sustained subsidies. Indeed, focused Federal support on near-term development can even be counterproductive. In the few years that a large Federal energy effort has existed, for example, the push for rapid commercialization has led to a marked shift from long-term research toward short-term results. As a consequence, there has been a decline in radically new ideas and even in the applied research essential to ensure the success of existing projects (NRC–14). Moreover, direct Federal support of industrial R&D is fraught with the difficult problem of proprietary rights. For those reasons, the Reagan Administration has chosen to focus more on indirect means, such as changes in tax laws and regulatory policies, than on direct means to encourage industry to increase its long-term research investments and to improve the climate for commercializing results of R&D activities.

UNIVERSITY-INDUSTRY COOPERATION

Given that industry primarily does applied and developmental research and will continue to do so, and given that university research is primarily basic and will continue to be so, increased linkages between industries and universities have an obvious appeal in that their research is complementary, and such linkages promote the interplay between technology and science. At present, cooperative programs between industry and universities account for no more than about 5 percent of the financial support for university research. But interest in such cooperation appears to have increased considerably during the past 2 or 3 years, and this may be one of the most significant current trends affecting both the science and technology base and the innovative capability of U.S. industry (NRC–14; AAAS–2).

Both groups have a great deal to gain from closer cooperation. Industry can facilitate its acquisition of scientific sources of ideas and knowledge on which to base new technology. Industry can also easily make use of competent scientists from around the country without expanding in-house capabilities. Furthermore, such cooperation increases the pool of potential research employees sympathetic to industry's needs, since many students would probably become involved in the cooperative research activities.[11]

There are also obvious benefits for universities. Industrial research support complementary to Federal funding could be increased. The industrial connection would also provide a broader educational experience and additional potential employment opportunities for students. In addition, university faculty could be stimulated through interaction with industrial scientists and engineers and through access to specialized equipment.[12]

There also are some potential disadvantages in university-industry cooperation. For example, increased involvement with industry should not unduly alter university research programs from their basic research orientation toward applied and development-oriented projects. On the industry side, loss of proprietary information must be guarded against. But those constraints are not insurmountable, as long as research cooperation is in the area of overlap between basic and applied research and between science and technology.

Although relatively rare, cooperative research projects between individual university and industry scientists or engineers arranged by the individuals themselves have gone on for many years. The recent trend toward increased cooperation involves more formal commitments between institutions rather than between individuals. Forms of cooperation vary considerably and include personnel exchange programs, unrestricted grants to universities or university departments, contracted research, jointly owned or operated research facilities, and university-based institutes that serve industrial needs. At present, most cooperative research programs are in the engineering disciplines, computer science, and agriculture. There are also some cooperative research efforts in the physical sciences, and the merits of closer university-industry research links in the biomedical area are being widely discussed.[13] One interesting development has been the support provided by several State governments to establish university research facilities that can attract cooperative funds from private industry for research on very high speed integrated circuits.

The Federal Government is playing a role in encouraging cooperative activities in several critical areas.[14] The Department of Defense supports industry-university cooperative research on very high speed integrated circuits (Section II-B). Additionally, there is the Defense Advanced Research Project Agency (DARPA) Joint Research Program in the materials sciences within the Department of Defense, and the Office of Naval Research has a Selected Opportunities Program, which specifically encourages joint university-industry projects. The National Science Foundation provides support for cooperative research activities through its Industry/University Cooperative Research Projects and University/Industry Cooperative Research Centers programs.

Given the potential benefits to both parties, university-industry research cooperation is almost certain to increase during the next 5 years, with or without added Federal incentives. The increased activity should permit an evaluation of the relative effectiveness of various cooperative modes and should also provide information on which to develop guidelines about the effectiveness—and appropriateness—of Federal support for such cooperation. An indepth review of the current state of university-industry cooperative research will be provided by the 14th Report of the National Science Board, due for release in the fall of 1982.

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D. The International Context of U.S. Science and Technology

Increasingly, the products of science and technology force issues that are traditionally domestic in character into an international context and also place new issues on the international agenda (AAAS–6). During the next 5 years, events and trends outside the United States will likewise have impacts both on the conduct of U.S. science and technology and on the relationships of science and technology to U.S. domestic problems.

Such trends and developments can conveniently be divided into four categories:

(1) Developments in science and technology that the U.S. science and technology enterprises, and therefore the United States, can use to their own advantage;
(2) Developments and trends in science and technology and in science and technology policy that could affect the competitive economic, diplomatic, or military standing of the United States;
(3) Problems and opportunities of a transnational character related to advances in science and technology that are likely to affect the United States or the U.S. science and technology enterprise; and
(4) Global problems affecting international stability that U.S. science and technology might help resolve.

Developments and trends in the first two categories raise the broad problem of how best to balance the desirability for international cooperation in science and technology with the need for the United States to maintain its competitive position next to countries whose science and technology are roughly comparable to ours. The two categories primarily involve relations between the United States and the industrialized democracies and between the United States and the U.S.S.R.

Examples of problems in the third category include those associated with international resource management, the global environment, and international information and communications capabilities. They involve U.S. relations with all of the industrialized countries and, additionally, with a number of less developed countries that have some advanced science and technology capabilities, including Mexico, Brazil, India, Pakistan, Korea, and several OPEC countries.

Problems in the fourth category are related to the perennial, overriding issue of world poverty. They include population and the adequacy of world food and energy supplies and involve U.S. relations with all countries of the world.

U.S. SCIENCE AND TECHNOLOGY RELATIVE TO OTHER INDUSTRIALIZED DEMOCRACIES

Human and financial resources available for the conduct of R&D remain considerably greater in the United States than in any of the leading industrialized democracies, principally the Western European countries, Canada, and Japan. However, several of those countries are closing the gap in terms of total investments, and, significantly, investments in those countries are concentrated in areas closely related to productivity and economic growth (*SI–80*). In addition, U.S. preeminence in both science and technology is being increasingly challenged from abroad (See Sections I-B and I-C).

Whether the gaps will continue to narrow or whether, on the contrary, investments in R&D elsewhere will decline or plateau at lower levels than in the United States (as they have in the United Kingdom and France) cannot be answered at this time. Certainly the other countries have also been experiencing economic problems that may affect their abilities to maintain and develop science and technology bases. However, in view of the current economic situation in the United States, the decreasing U.S. advantage in science and technology relative to many of the industrialized democracies is bound to be of continuing concern during the next 5 years.

One factor that could have an appreciable influence on the competitive economic position of the United States is the effect on industry of U.S. environmental, health, and safety regulations. Since regulatory policies in this country have in the past differed from policies in other industrialized countries, the resultant additions to production costs in the United States may in some cases place American industries at a competitive disadvantage (AAAS–6). A notable example is the American pharmaceuticals industry, which is unable to market certain products in the United States because of stringent testing procedures and, as a result, has been increasing its foreign R&D investments more rapidly than its domestic investments (NRC–14). President Reagan's regulatory reform policies are expected to help address this problem.

There may also be temptations during the next 5 years to erect barriers against foreign imports to protect certain endangered U.S. industries. However, because of resulting decreases in the incentives for industrial innovation that normally accompany competition, such a course for protecting against competition might lead to decreases in needed R&D investments, with undesirable long-range economic consequences (AAAS–6).

Reciprocally, the issue of limiting U.S. exports of high technology to the industrialized democracies is likely to be debated. Since the export of U.S.-developed technology can increase the relative competitive positions of other countries, an important question is: Does the monetary return to the United States for exported technology adequately reflect the likely long-range costs in terms of increased foreign competition? In approaching an answer however, it is important to note that much technology is transferred through American-owned subsidiaries in foreign countries and is therefore difficult to control. In addition, any protectionist measures that could lead to countermeasures against this country must take into account the important contribution to the U.S. balance of trade from the exports of R&D-intensive industries at a time when non-R&D-intensive industries have been registering trade deficits (*SI–78*).

While technological competition with the industrial democracies clearly is increasing, so are opportunities for cooperation in a range of science and technology activities. Incentives for such cooperation in increasingly expensive R&D projects are likely to increase. The science and technology capabilities of many of the industrialized countries are roughly comparable to those of the United States, as are some of the economic problems they face. Inflation rates were generally higher in all those countries in the late 1970s than they were during the previous decade. In addition, rising energy costs and the continuing threat of interruptions in imported petroleum supplies are serious problems.[1]

A recent report of the Organization for Economic Cooperation and Development (OECD) highlighted a number of problems related directly to science and technology that are shared by the industrialized democracies:[2]

(1) There is concern about an overall slowdown in industrial innovation, productivity, and economic growth and recognition that a strong capacity for industrial innovation will be increasingly important in the future. Consequently, the desirability for better coordination of R&D with the total system of engineering, manufacturing, and marketing and for integrating science and technology policy more closely with general economic policy is widely recognized. In the United States, recent tax and patent policy changes are expected to foster industrial innovation.

(2) Broadly, there is recognition that external social factors may limit the potential contribution of science and technology to economic growth and social advance. There is concern, for example, about the effects of environmental, health, and safety regulations on industrial innovation and productivity, and there is recognition that disparities in regulatory policies among the industrialized countries need to be minimized. As mentioned earlier, the Administration's regulatory reform initiatives are expected to ease the burden of regulations on America's industries.

(3) There is general agreement that the financial and human resources for conducting R&D are likely to be constrained during the 1980s. Hence, there is recognition of a need for improving both project selection and evaluation procedures to optimize the use of available resources.

(4) Given those resource constraints, there is concern about the danger of providing insufficient long-term investments in research capabilities. Considerable concern exists about the decreasing growth rate of academic research and the consequent recognition of the desirability to take steps to preserve support for basic research. There is a growing recognition that a great deal of fundamental research in engineering shares common characteristics with traditional basic research in science and, therefore, needs similar levels of support and protection.

International science and technology cooperation could help alleviate some of the problems. Cooperative government-to-government programs with other industrialized countries are especially beneficial to the United States when the cost of solving problems is high and when the problem area is remote enough from commercial application possibilities so that proprietary considerations do not dominate. Examples of such activities now ongoing include advanced energy research and development and space research. The United States and Japan are cooperating in a number of advanced energy-related research programs, especially in fusion research, and we cooperate with several other countries in advanced fusion R&D (ENERGY).

In addition to such official bilateral and multilateral programs, cooperation between individual American scientists or private firms and their foreign counterparts should continue to provide opportunities for stimulating advances in U.S. science and technology. It is particularly noteworthy that the considerable investments of U.S. firms in R&D abroad result in benefits to the U.S. economy as well.

There may also be some important lessons for the U.S. science and technology enterprise to learn from the experiences of other industrialized countries. For example, in France, West Germany, and, to a lesser extent, the United Kingdom, a considerably higher proportion of basic research is carried out in national laboratories and nonuniversity research institutes than in the United States, where the bulk of such research is done in universities or laboratories managed by universities. Indeed, there are few U.S. counterparts to the nonuniversity system of research institutes supported by the French and West German governments; our national laboratories are among the few examples. Those laboratories and institutes, as well as European research universities, are guaranteed base levels of research support from their governments, and those base levels can be augmented by special project grants. In contrast, about 60 percent of academic research in the United States is supported solely through the project grant system. Research funding typically is for longer time periods in those European countries than in the United States. These factors can provide the stability required for carrying out long-term speculative research projects. Moreover, longer term funding and/or greater provision of base support reduces the administrative burden on individual scientists (NRC–13).

On the other hand, there are disadvantages to the European system and obvious hazards would accompany trying to use the European system as a guide for long-range planning in the United States. For example, the integration of teaching and research has been essential to the U.S. academic system, and any weakening of those links should not be undertaken lightly. Moreover, European specialists are themselves concerned about the declining growth rates of academic research, indicating that they have not yet solved the problem of support to their own satisfaction.[3] However, since the pressures on university research as it is presently conducted in the United States are likely to persist, it may be worth investigating the European experience in greater detail to determine which elements, if any, could be transferable (NRC–13).

U.S. SCIENCE AND TECHNOLOGY RELATIVE TO THE U.S.S.R.[4]

Together, the investments of the United States and the Soviet Union account for a large majority of total world investments in science and technology. The Soviet Union has long recognized that progress in science and technology is essential to both military and economic development.

Available information suggests that the resources committed to conducting science and technology in the Soviet Union are quite extensive. The ratio of national R&D expenditures to the Gross National Product in the U.S.S.R. rose above that of the United States in 1967, and it now is the largest in the world (*SI–80*). Cost estimates for military research, development, test, and evaluation (RDT&E) expenditures indicate that the Soviet Union has probably exceeded annual U.S. expenditures in those areas during each of the past 10 years and that RDT&E enjoys an increasing share of Soviet military outlays (NS). On the other hand, overall U.S. R&D expenditures still exceed those of the U.S.S.R., and U.S. civilian R&D expenditures are much larger than those of the Soviet Union. The human resources committed to science and technology activities in the Soviet Union also appear relatively more extensive, although the emphasis is again on military R&D (*SI–80*).

Soviet scientists and engineers have made impressive contributions in a number of fields. They include, among the fundamental sciences: mathematics, theoretical physics, astronomy, and accelerator development. Most notably, the U.S.S.R. has made significant strides in both civil and military space applications and in applying R&D to national defense. While the United States maintains its leadership in most of the basic technologies critical to defense, the Soviet Union is closing the gap in several key technologies, including electro-optical sensors, guidance and navigation, hydroacoustic technology, optics, and propulsion (NS).

However, in spite of its impressive achievements in these and a few other areas, the overall results of the massive Soviet commitment to science and technology have been less than might be expected. The U.S.S.R.'s failure to apply science and technology to increasing agricultural productivity is well known, and the U.S.S.R. is far behind the United States in the development and use of computer and communications technologies. More generally, the Soviet Union has been relatively unsuccessful in exploiting R&D for innovations in manufacturing industries and for purposes of economic growth.

American (and Soviet) analysts have pondered the causes of this disappointing performance for years. During the Stalin years, the need for scientists to demonstrate ideological purity inhibited advances in several scientific fields, most notably genetics.[5] The present harrassment of dissident scientists by the Soviet government and the overall climate of suspicion and secrecy also affect scientific advances. However, the problem of using R&D results appears to be most closely related to the nature of the Soviet economy. That the economy is centrally planned has created rigid institutional barriers between the R&D sector and the industrial sector, and the absence of strong economic driving forces is inhibiting innovation and economic growth.[6]

Integrating R&D planning with general economic and, particularly, industrial planning and devising means for better selection and evaluation of science and technology goals have preoccupied top Soviet leadership since the early 1970s.[7] While figures on Soviet productivity directly comparable to U.S. and Western European data are unavailable, little progress seems to have been made in the U.S.S.R. However, there are indications that the Soviet Union is becoming far more adept in implementing advanced R&D for military purposes (NS).

The Soviet government has recognized the need for a high degree of science and technology literacy among the general labor force and has instituted a general curriculum reform at primary and secondary levels that focuses heavily on science and mathematics. While the extent to which those reforms have been implemented is not clear, and while it is too early to evaluate their effects on the quality of the labor force, U.S. specialists agree that, at least on paper, Soviet precollege science and mathematics education is the best in the world.[8]

The Soviet Union also shares with the rest of the world concerns about energy development. The country has considerable reserves of oil and natural gas and, at present, exports both, particularly to the Warsaw Pact nations. The Soviet Union also has vast coal resources, a small fraction of which it is exporting. However, it has a long way to go to realize the full potential of those reserves for direct use or as the basis of a synthetic fuels industry.

The implications of Soviet trends in science and technology for the United States and its science and technology enterprise are neither simple nor, as of yet, clear. American policymakers and individual American scientists are frequently faced with difficult decisions about the appropriate degree and form of science and technology cooperation with the Soviet Union. For example, there is the question of high-technology exports to the Soviet Union. While the U.S.S.R. should clearly be denied access to specific advanced military technologies, the question of whether or not to export technology to the U.S.S.R. in other cases is less clear.

Similarly, in the case of bilateral scientific exchanges with the Soviet Union, the question of reciprocity is central. While the Soviets do excellent work in many fields, American scientists have often been frustrated by the far greater controls and secrecy of Soviet society. Access to the best scientists and facilities in the Soviet Union has often been blocked even when the overall political climate was favorable. Soviet scientists are not allowed to travel freely, nor are most national scientific conferences held in the U.S.S.R. open to Western scientists. Many U.S. scientists have also faced difficult personal choices on whether to participate in exchanges with the Soviet Union, when fellow Soviet scientists, like Nobel Laureate Andrei Sakharov, have been exiled or imprisoned.

There is a clear linkage between the scientific exchanges and the overall political relationship with the Soviet Union. This was most clearly demonstrated after the Soviet invasion of Afghanistan and the exile of Sakharov, but there had been earlier linkage in 1976 at the peak of Soviet proxy intervention in Angola and in 1978 with the trials of Soviet scientists Orlov and Scharansky.

The Soviet Union's role in abetting the suppression of the Solidarity Movement by the Polish government in December 1981 provides the most recent evidence of the need for caution in predicting the future course of all interactions, including science and technology interactions, with the U.S.S.R. The prospects for the next 5 years will depend on the overall political climate and on the degree of reciprocity in the ongoing exchanges.

TRANSNATIONAL PROBLEMS AND OPPORTUNITIES

A number of transnational issues associated with advances in and applications of science and technology are likely to intrude themselves on the U.S. domestic agenda during the next 5 years. They include resource development and management, the global environment, and transborder information flow.

RESOURCE DEVELOPMENT AND MANAGEMENT

Relative depletion of oil and natural resources in the United States and the uneven geographic distribution of certain essential materials have resulted in the Nation's vulnerability to limitations or interruptions in the supplies of rubber and some primary metals, as well as oil. Other industrialized countries and some middle-tier countries of the third world share those problems.

As discussed in Sections II-E and F, short-term resource vulnerabilities of the United States and its allies do not lend themselves readily to science and technology solutions; they generally are due to political and economic factors. However, science and technology can play major roles in the longer term. Applications of R&D to resource exploration, recovery, processing, and use could offer a major part of the solution to domestic—and international—resource supply problems. Given resource distribution patterns and the long leadtimes and large capital investments required to exploit science and technology to this end, it is not feasible for a single country to carry the burdens alone. Therefore, a commitment of R&D resources to those objectives—by U.S. industries in concert with those of other industrialized nations—might be one profitable approach to be taken during the next 5 years (AAAS–6).

Another important resource management problem requiring international attention during the next 5 years is the rapid disappearance of tropical forests that are being cleared in less developed countries to provide more land for agriculture and other commercial purposes. The continued degradation of the world's tropical forests is particularly serious, since reforestation is not usually possible. Continuing loss of tropical forests would accelerate the rate of extinction of tropical plants and animals and undercut needed water development projects in certain countries (Section II-F). It would also affect the availability of certain woods of importance to the United States and, by decreasing the amount of carbon dioxide reabsorbed from the atmosphere, could contribute to global changes in weather and climate. In December 1980, a U.S. Goverment Interagency Task Group produced a report on tropical forests that defines several immediate scientific and policy goals. Recommended R&D approaches include a world analysis of the rates and causes of tropical forest loss, further study of ecosystem dynamics and forest management techniques, and major international programs to inventory, evaluate, classify, and catalog unique forest plant and animal types (IA).

A final example of essential transnational resource management and development problems concerns protection of the world's arid lands. Since most of those areas are in the poorer countries of the world, research aimed at the control of desertification has consequences for avoiding famine and human dislocations and can, therefore, be classified as a global rather than as a transnational concern. However, there are also many areas in the United States threatened by desertification and, therefore, a good deal of arid land research has implications that could lead to better general land management in this country. Such research also could have important consequences for Mexico, which, as far as U.S. interests are concerned, is one of the most important of the middle-tier countries. The United States and Mexico have executed a joint agreement on Arid Lands Management and Desertification Control, which establishes a joint research program to combat desertification along their common border. Positive results of activities taken under the auspices of the agreement should emerge during the next 5 years (IA; *ASTR–III*).

INTERNATIONAL ENVIRONMENTAL ISSUES

Pollution of the oceans and the consequent threat to their living resources will continue as a transnational concern for the indefinite future. The Intergovernmental Maritime Organization Marine Pollution Convention articulates international enforcement and protective procedures to control vessel-related pollution, most notably oil spills. However, since 90 percent of the pollution of the marine environment arises from land-based sources, a wider ranging set of international conventions will be needed to control the ocean environment (IA). No dramatic effect can be expected during the next 5 years, since establishing control will be a long-range, multifaceted endeavor. But small steps can be taken and are essential.

Pollution of the atmosphere is a second transnational environmental problem requiring continuing attention. The problem of acid rain (or more properly acid precipitation) associated with burning fossil fuels is discussed in further detail in Section II-G. There is marked concern in the Scandinavian countries about the effects of pollutants from the United Kingdom, and there is some evidence that acid rain from U.S. sources may be causing ecological damage in Canada. Therefore, the transnational atmospheric pollution problem requires focused attention and no doubt will be discussed a great deal during the next 5 years (*ASTR–III*; AAAS–6; ENVIRON).

Potential depletion of the ozone layer due to emissions of fluorocarbons and other industrial materials, with possible resultant damage to plant, animal, and human life, is another serious although much more long-term problem. Additional research on the effects of industrial emissions on the ozone layer and, consequently, on living organisms is progressing. The results should provide means both for a better assessment of the hazards involved and for the eventual development of an effective, equitable international regulatory regime, although no dramatic progress is anticipated during the next 5 years (IA).

Increasing atmospheric concentrations of carbon dioxide from all forms of fossil fuel combustion and, perhaps, from deforestation could ultimately become the most serious of all atmospheric pollution problems. It could be exacerbated by excessive deforestation and the resultant decrease in the capacity of the earth to reabsorb carbon dioxide from the atmosphere. Increased concentrations of atmospheric carbon dioxide could raise Earth's surface temperature sufficiently to shift world patterns of agricultural production and, by partially melting the polar ice caps, raise ocean levels appreciably. However, since there are considerable uncertainties about the details of the complex mechanisms involved, there is considerable uncertainty about what the consequences of different levels of fossil fuel combustion will be. Hence, further research on atmospheric processes and on world climate patterns is required. The next 5 years could be critical ones for carrying out the research needed as a base for decision-making about how to deal with this problem (ENERGY; IA).

GLOBAL ISSUES

The final set of international issues likely to have an impact on U.S. science and technology in the future arises not so much from the results of science and technology, but from the continued expectations of less developed countries that science and, more particularly, technology can provide a key to their economic development. That expectation remains strong despite the fact that at present only about 5 percent of the world's science and technology resources are directly focused on problems of world development (AAAS–6).

Three large related problems constrain economic development in the third world: continued population growth, rising pressures on the world food supply system, and increasing world demand for petroleum. Science and technology have made and can continue to make important contributions to relieving those constraints and, perhaps, buying time for economic development.

POPULATION

The extraordinary force of recent changes and present trends in the world's population has no precedent in human experience (NRC–1; AAAS–9). World population increased by 1.9 billion, or over 75 percent, from 1950 to 1980 (Figure 7). The rate of population growth is now declining modestly, but it remains at an extraordinarily high level by all standards of past experience. For example, the population of Asia in 1980 (2.558 billion) was slightly larger than what the total world population was in 1950 (2.513 billion). Current projections of the world population in the year 2000 cluster about 6 billion, a 40 percent increase above the current level (AAAS–9). The ultimate steady-state world population would occur when a situation of fertility replacement (the so-called two child family) is reached, and current projections are that the world population will stabilize in the late 21st century at around 9 billion people (NRC–1). Even with the uncertainty in these population projections, their implications for the world of the future could be very serious, particularly in terms of food, energy, minerals, and international security (AAAS–9). The severity of the effects of world population growth is dependent, however, on concomitant levels of scientific and technological advance. For example, current progress in world agriculture and industry suggests that world food and other production could double in the next century. If those advances do occur, one could be relatively secure about the overall population/resource ratio for an ultimate 9 billion people (NRC–1).

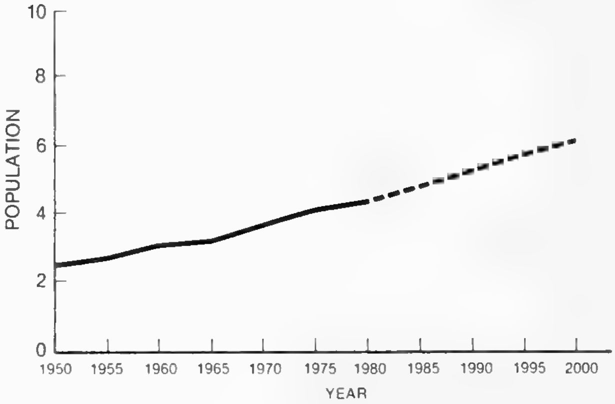

FIGURE 7. Population (Billions) in the World, 1950 to 2000.

Note: Trends are given as they were assessed in 1978. 1950–1980 data are estimates, 1985–2000 are projections. 1980 data are projections from mid-1975 data, but may be viewed as best available estimates for 1980. Source: W. Parker Mauldin, "Population Trends and Prospects," *Science*, Vol. 209 (July 4, 1980), p. 156.

But, such optimism may not be justified when individual countries and regions are considered. Given expected technological advances, Earth's overall carrying capacity probably will not be exceeded, at least through the 21st century. But, there are now and will continue to be severe population/resource problems in some countries, particularly the less developed ones. Thus, a global approach to the relationships between population and resources is inappropriate; cases should be considered individually. Bangladesh, for example, currently has little prospect of attaining an acceptable balance between its population on the one hand, and its land and other resources on the other (NRC–1). In addition, migration rates within some countries, primarily from rural to urban areas, are increasing dramatically. In the less developed countries, urban growth rates are about double the high national growth rates. Unprecedented urban agglomerations will appear in the next 20 years, suggesting awesome problems in the quality of urban life. International migration—legal or illegal, temporary or permanent, political or economic—is also growing, implying major dislocations and greater demands for food, mineral resources, and energy in some countries (NRC–1).

In short, what is needed over the coming years is recognition of, and attention to, the unequal distribution among independent nations of population and resources, and the possible role of science and technology in mitigating the potential negative impacts of that unequal distribution (NRC–1). The question of the appropriate U.S. role in that and other aspects of world science and technology development is discussed below and in more detail in the accompanying *Source Volumes* (NRC–1; AAAS–6; AAAS–7; AAAS–9).

FOOD AND AGRICULTURE

Improved worldwide agricultural production will be required both to supply needed amounts of food and as a central aspect in an effective worldwide attack on such related issues as malnutrition, poverty, inflation, unemployment, and population pressures. The United States is the world's greatest producer, consumer, and exporter of food, and that agricultural capacity is important to America's current international economic position (AAAS–8; AGR). Many analysts argue, however, that the United States cannot carry indefinitely the major burden of food production for the world. American land resources that can be allocated to food production are limited and can rapidly be depleted if misused, and continued high levels of agricultural exports could raise domestic food prices to unacceptable levels. In response to those constraints, the United States can play an important role in increasing the food production independence of other nations through scientific and technological cooperation, thereby relieving some of the political and economic stresses that destabilize international relationships (AAAS–6; AAAS–8). Increasing agricultural productivity in the less developed countries will be difficult given the severe constraints imposed by expensive energy and limited land and water resources. It will require the development and use of new technologies that provide maximum productivity for a given set of input conditions and that take into account potential environmental impacts (AAAS–8; AGR). That topic is discussed in greater detail in Section II–I.

The important contributions that basic research in biology could make to solving a range of agricultural production problems deserve particular mention. They include development of more water-efficient, salt-tolerant, and stress-resistant plants; development of plants capable of fixing nitrogen from the atmosphere; and methods for effective pest and disease control. Revelle notes, in this connection, that the field of biology is in its infancy (compared with physics and chemistry, for example) in the sense that most fundamental discoveries remain to be made.[9] Investments needed to conduct basic research in biology are also considerably less than for the physical sciences. Those three circumstances—the applicability of biology to agriculture, the relative newness of the field, and the relatively modest investments required to pursue it—commend biology as a promising discipline for development in third world laboratories and in institutions in the industrialized countries that seek to optimize their contributions to economic development.

ENERGY AND DEVELOPMENT IN THE LESS DEVELOPED COUNTRIES

The energy problem is particularly severe for those less developed countries that have no appreciable fossil fuel resources. Rising petroleum prices have placed many of them under crushing burdens of debt and have forced them to curtail development plans. By the same token, importing coal from one of the major potential future exporters (Australia, the United States, the U.S.S.R., or the People's Republic of China) would be feasible only if exports were sufficient to earn the currency needed to pay for it. Nuclear power may be an option for some, but not all, middle-tier countries. Thus, except for a few special cases, solar energy may seem to be the primary available option. But, even that option is limited, since the poorer countries are unlikely to be able to afford the sophisticated material-intensive solar devices that may ultimately provide appreciable energy in the industrialized countries.

Those circumstances lead to the conclusion that using biomass for energy may be the best hope for the fossil fuel deficient countries of the third world.[10] Indeed, many of the steps that could be taken to improve food production, including investments in basic research in biology, could also facilitate development of local biomass industries. However, development of such industries even on a small scale would divert labor and, no doubt, some land from food production. While the effects of those dislocations can be mitigated by careful planning, it is unlikely that the energy dilemma facing the world's poorest countries can be resolved without causing some additional problems.

U.S. SCIENCE AND TECHNOLOGY AND WORLD DEVELOPMENT

A variety of mechanisms exist for direct technology transfer to less developed or developing countries: some involve private corporations, some are based on bilateral U.S. Agency for International Development (AID) assistance, and others involve transnational enterprises and international agencies. However, in order for the developing countries to make effective use of transferred technologies, they need the capability to set realistic objectives, to negotiate technical contracts, to weigh subtle choices among technologies, and, in general, to be aware of technological or economic options. That is, developing countries require a significant internal scientific and technological capability. Acquiring that capability can, in the long run, enhance economic performance. This has been demonstrated by such countries as India and Korea, where having sufficiently well developed science and technology infrastructures has allowed them to adapt and use acquired technologies effectively (AAAS–6; AAAS–7).

The United States has the potential to provide the type of continued assistance that will permit those countries to develop and strengthen their own science and technology capabilities (AAAS–7). In doing so, the United States may also be able to strengthen its bilateral relations with specific countries, as it has done with nations as diverse as Korea, Egypt, Saudi Arabia, and the People's Republic of China. Means that are available for fostering indigenous capabilities include training programs for technical personnel, assistance in establishing local institutions to evaluate and use acquired technological capabilities, and fostering local science and technology programs. The United States has participated in a range of those assistance efforts over the past 20 years, as have many other industrialized countries. These levels of effort have been sponsored under both public and private sector auspices. However, many analysts believe that a greater commitment to those ends is demanded of the industrialized countries (AAAS–6; AAAS–7).

Achieving effective technology transfer is not without difficulties. In addition to the problem of insufficient indigenous scientific and technical capabilities, there are problems related to the nature of the technology to be transferred. Technologies suitable for, or appropriate to, problem solving in the industrialized nations may not be appropriate for use in the developing countries. In many cases, adoption of technologies that are routinely applied in industrial countries can cause major social and political disruptions in the developing countries, such as increased unemployment. Therefore, technologies frequently must be modified or adapted to local needs and conditions, and both determining the appropriate form and, then, achieving the technology transfer can be difficult tasks (AAAS–7).

There also are major legal/political constraints on technology transfer from the industrialized to the less developed nations. One major problem concerns proprietary rights. Most industrialized democracies are signatories to international conventions governing questions of who owns the patents to technologies. However, the less developed countries frequently are not. Therefore, patent rights often appear to have no force in the less developed countries, and that can impede the technology transfer process. Constraints on technology transfer will require continued debate and action in the coming years before such transfer can be accomplished both expeditiously and equitably (AAAS–7).

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E. Science, Technology, and Policymaking

The empirical data derived from scientific research, coupled with the conceptual and analytic tools developed by various scientific disciplines, can provide a systematic means to help define and illuminate many current and emergent problems on the national policy agenda (AAAS-Obs.). Many, though by no means all, of those problems are associated with science and technology themselves. Additionally, science and technology can contribute concepts or constructs that lend precision to decisions and to views of the world about which decisions must be made, although, of course, science and technology cannot provide a complete basis for decisions about issues that involve value choices and political judgments (SSRC–1). Since science cannot provide the sole basis for policy decisions, methodological and policy debates are likely to continue to surround the application of scientific concepts and methods to the assessment of national issues: first, because there are always residual uncertainties associated with attempts to measure, interpret, or predict the future course of the complex physical, biological, ecological, or social systems associated with national policy; second, because measurements themselves and (particularly in the case of the social and behavioral sciences) the interpretations that emerge from them often touch upon or challenge deeply held individual or social values.

Despite the limitations of science as a policymaking tool, three convergent trends suggest the increasing importance of devising more systematic and broadly acceptable ways to use information derived from the full range of the natural, social, and engineering sciences in the decisionmaking and policymaking processes.

First, both the time frames and the financial resources needed for research and development have been increasing, as has been the importance of science- and technology-based innovation to our national well-being. Hence, better scientific information and better knowledge about its potential application will be needed to make informed decisions about the allocation of resources for research and development activities in both the public and the private sectors (NRC-Obs.). Some general issues associated with the allocation of resources for research and development have been treated in Sections B and C of this chapter, and others are highlighted on a case-by-case basis in Chapter II.

More broadly, scientific data, constructs, and methodologies have become essential tools for making policy decisions in areas not so directly related to scientific and technological activities and developments. Such concepts as externalities, identity crisis, Gross National Product, assimilation, the hidden economy, and unanticipated consequences have provided the basis for organizing the empirical data needed for assessing the social and economic condition of the country and for forecasting probable consequences of various policy alternatives (SSRC–1).

The second notable trend is the phenomenal expansion in both the amount of available information and the electronic capabilities for handling and providing access to it. As the information revolution penetrates more deeply into the U.S. social and economic fabric, issues related to the production, transmission, and use of the expanded and more accessible pool of information, including scientific and technological information, will become increasingly important (AAAS–1; AAAS–3; AAAS–6).

Finally, there appears to be a growing perception that the regulatory mechanisms adopted during the 1970s to manage the risks that are inevitable outgrowths of our science- and technology-based industrial society may in some cases be inadequate and in others even counterproductive to achieving desired social goals. The role of the Federal Government in the regulatory sphere has in itself become an important policy issue. Thus, the need for better information and for improved analytical tools to assess, compare, and manage risks as a basis for developing regulations and to evaluate the costs and benefits of alternative regulatory strategies is likely to become increasingly pressing (AAAS–1).

The rest of this section focuses on those two latter trends and associated sets of issues: the availability of information, and the use of scientific and technological information in the regulatory sphere.

MAXIMIZING THE AVAILABILITY AND UTILITY OF INFORMATION FOR DECISIONMAKING AND POLICYMAKING

The rapid convergence of computer and communications technologies that constitutes the electronics revolution, and the effects of that revolution on several sectors of society, were treated extensively in the first *Five-Year Outlook* on science and technology and in its *Source Volume*.[1] Both the rapidity and the flexibility with which information of all sorts can be produced, processed, transmitted, stored, and retrieved have continued to grow during the past 2 years. That is particularly true of scientific and technological information. Examples of new opportunities afforded by the expanding information capabilities appear throughout this report.

CONSTRAINTS ON THE AVAILABILITY OF INFORMATION

While the total amount of available scientific information will continue to grow rapidly, specific types of information needed by decisionmakers may not be readily available. Scientific information is the result of scientific research, be it laboratory research, or survey or field research. Therefore, the availability of scientific information is constrained by the same internal factors (such as the state of knowledge in particular critical fields) and external factors (such as available financial, personnel, and equipment resources) that constrain scientific research itself.

Regulations on scientific activity are, in some cases, another important constraint on the availability of information that could be particularly useful for decisionmaking. Overly stringent informed consent protocols may, for example, limit the availability of critical survey or field research data (see below). Likewise, regulations designed to protect the confidentiality of individual medical records may limit the availability of data needed for epidemiological studies.

The availability of information for decisionmaking and policymaking is also constrained by data management problems. The rate at which both the production of scientific information and the information-handling capabilities have been growing qualifies as an information explosion. That situation has, in turn, increased the difficulties of aggregating needed information in a form useful for decisionmaking and policymaking. The sheer bulk of available information poses problems in sorting out the more usable, better quality materials from those of lesser quality. Current information-handling technologies do not have that capability and may even exacerbate the problem since they frequently "dilute" information for easy use. Some observers have characterized the whole set of problems, which can make the effective use of scientific and technological information difficult, as "information pollution" (AAAS–3).

CONCEPTUAL ISSUES

In some important respects, the problem of maximizing the availability of scientific information for policymaking and decisionmaking begins with the problem of maintaining and strengthening the science and technology base.

However, not all scientific information is directly usable for helping to define and illuminate national policy issues, in part because the goal of research in many disciplines such as mathematics, radio astronomy, high-energy physics, and molecular biology is to obtain a deeper understanding of nature rather than to provide reliable information and tools to assist in decisionmaking outside the disciplines themselves. There are, however, scientific disciplines in which principal research goals are directly related to improving the quality of the information needed for weighing policy options.

Survey methodologies, for example, provide means for sampling the characteristics, actions, or opinions of large groups of people. By yielding information about such things as voter preferences, unemployment rates, or the market intentions of consumers, the results of such surveys can aid decisionmaking in both the public and the private sectors. Commercial enterprises, for example, make heavy use of survey data and demographic projections in deciding where to locate offices or retail stores and in choosing products to produce and the marketing strategies to follow (SSRC–1; SSRC–3). The Federal Government, in turn, often uses survey data as a base for the allocation of funds or as a basis for designing public programs (SSRC–3).

Likewise, during the past 20 years, a great deal of effort has been focused on developing sound sets of data about the current status of various institutions, such as industrial firms, educational institutions, and the government, and about the ways in which their status changes from year to year. Collectively, those social indicators provide a broad view both about the state of society at a given time and about its rates and forms of change. For example, government officials, businessmen, and the larger public frequently are asked to address problems associated with current and changing patterns in such societal elements as crime, the birth rate, health care, and employment opportunities. Having the necessary factual information about the current status and rate of change of such conditions is crucial, both to making informed and appropriate choices among options and to framing effective policies (SSRC–5).

Such indicators are regularly applied to the science and technology enterprise and are published biannually in the National Science Board's series, *Science Indicators*. Those indicators are used to inform decisionmakers about the effects of science and technology activities on areas of national concern, such as industrial productivity, and, reciprocally, about the impacts of public policy upon science and technology. That is, they can provide a basis for framing science policy and for maximizing the contribution of science and technology efforts to the national well-being (SSRC–5).

Additionally, related methodologies are frequently used to predict and evaluate the effectivess of planned policy actions, and they can aid in the design, conduct, and interpretation of the results of pilot projects. For example, the Federal Government has sponsored experimental pilot programs to evaluate, using social science concepts and methods, the potential impacts of such proposed national efforts as income maintenance, health insurance, and housing subsidies (SSRC–1). The evaluation of the effects of Federal regulations is a special, important case, as discussed in the next subsection.

SCIENCE AND REGULATORY PROCESSES

On February 17, 1981, the President issued an Executive Order calling for greater precision in assessing both the need for, and the potential impacts of, a broad class of Federal regulations.[2] Subsequently, the President's Task Force on Regulatory Relief was established under the chairmanship of the Vice President to conduct a broad assessment of Federal regulatory laws and policies. Those actions reflected a widespread opinion that the Federal Government overreacted during the 1970s in framing regulations to eliminate or minimize risks to health, safety, and the environment associated with, or resulting from, scientific and technological activity. While few would question the desirability for some controls over particularly hazardous products and processes, there is evidence that some Federal regulations have had negative impacts on industrial innovation and on advances in science and technology (Sections I-B and I-C). The President's February 1981 order requires the positive and negative effects of regulations to be weighed against each other. Whatever the specific recommendations of the President's Task Force turn out to be, they will almost certainly be designed to improve the rational basis for establishing regulatory priorities. Thus, there is a clear need for detailed information about risks and their impacts and for analytical tools for weighing risks, costs, and benefits.

How, then, can science and technology be used in assessing risks and weighing alternative strategies for eliminating or mitigating those risks? The first step involves the identification of risks. To that end, it is useful to consider two classes of risks: those associated with the results of science and technology and those associated with the conduct of science itself.

The first type of risk is exemplified by the hazards associated with the production, use, and disposal of toxic chemicals. The reasons that toxic chemicals are candidates for some type of regulation are obvious: virtually all chemicals, in sufficiently large concentrations, can cause damage to health, safety, or the environment; a few can cause damage even in minute quantities. Thus, some sort of control is required on chemical production, use, and disposal. Recognition of the need for control is the point at which the appropriate form and extent of regulation become issues.

An example of the second type of risk includes those associated with biomedical research on human subjects. In that case, regulations govern the activities of scientists, rather than the products of those activities. Again, the reason why biomedical research is a candidate for regulation is obvious: to protect individuals from excessive physical or psychological harm resulting from being subjects of that research. However, without research on human subjects, no new drugs could ever be tested and marketed, nor could new medical or surgical procedures be developed. Recognition of the conflict between the potential benefits to be derived from research using human subjects and the potential harm to the subjects themselves makes the form and extent of regulation of research on human subjects a particularly difficult policy problem.

Science can make two kinds of direct contributions to framing regulatory policies for the assessment and management of risk. First, it can supply empirical data about the prevalence and effects of a given set of potential hazards. Second, it can provide a battery of analytical techniques for assessing invariably complex situations and for evaluating the effects of alternative regulatory strategies (SSRC–1).

Science can also contribute indirectly to other aspects of policy decisions about the management of risk. For example, a major question concerning risk management is: What levels of damage to health or to safety or to the environment from a given technological advance are acceptable? It is now widely recognized that achieving zero risk while still reaping the benefits of scientific and technological advance is impossible. Therefore, a question that remains is: What level of risk is tolerable or acceptable? (NRC–Obs.; AAAS–5). Answering that question requires an understanding of public values about health and environmental quality, as well as an understanding of the values placed on the benefits that might also be derived from the technology. Scientific methods can be used to gather information about public perceptions and values and, thereby, can contribute indirectly to the nonscientific aspects of risk management decisions (SSRC–1).

SCIENTIFIC ASSESSMENTS OF RISK

Scientific contributions to risk assessment often involve two different types of research and analysis. First, measurements have to be made both to establish, quantitatively, the levels at which the hazard (a suspected toxic chemical, for example) occurs in various settings (such as a factory or dump), and to relate different levels of occurrence to different classes or degrees of damage to health, safety, or the environment. Other types of measurements may also be necessary—for example, atmospheric transport and absorption rates in the case of air pollution from coal-fired power plants.

Making those types of measurements and establishing precisely the necessary correlations are often very difficult. Estimating specific levels of possible damage can be greatly facilitated by a detailed understanding of fundamental physical, chemical, psychological, and biological processes, but even in those cases some residual uncertainties are common. The situation is further complicated in some cases since the sensitivity of instruments capable of detecting such things as contaminants in food, water, or the atmosphere is continuing to increase, so that minute traces may be found in previously unsuspected situations. Furthermore, there are cases where there may be no way to quantify risks, such as the potential psychological damage to a subject of a behavioral science experiment. In short, there is almost always a certain amount of residual uncertainty associated with scientific assessments of risk (NRC–Obs.; AAAS–5).

The second type of research and analysis required to assess risks involves extrapolation of present knowledge about hazard levels and their correlations with damage to health, safety, or the environment to future situations. In some cases, the extrapolations are relatively straightforward. In others, they are at best educated guesses and, as such, are open to debate. It is also particularly difficult to evaluate what might have been the risk of a particular drug that was never marketed or a power plant that was never built. Therefore, although high levels of precision are sometimes approached, there frequently remains considerable uncertainty in the analysis and measurement of risk. Risk assessment is not yet a sufficiently precise activity to cover all cases equally well or with equal levels of certainty, and further methodological refinements are needed. Dealing with the uncertainty increases the judgmental burden on policymakers.

WEIGHING RISKS, COSTS, AND BENEFITS

The issue of risk can never be resolved in its own right. That is, individuals and populations are never asked to accept a risk for its own sake. Rather, risks are acceptable only to the degree that they are a necessary price to be paid for anticipated benefits. It follows that any creditable regulatory policy has to be based on a comparison of risks and benefits, and on a broadly accepted consensus that the anticipated benefits outweigh the anticipated risks (AAAS–5). This need to weigh both the costs and the benefits of potentially hazardous technologies, as well as the costs and benefits of regulating those technologies, was recognized in President Reagan's Executive Order on Federal regulation.[3]

Thus, yet another type of research and analysis consisting of formal techniques for weighing sets of risks, costs, and benefits is sometimes brought to bear on risk assessment and management. The use of such cost-benefit analyses, however, it not without difficulties. During the past decade, there has been increasing interest in expanding formal methods of cost-benefit analysis to the realm of risk-benefit comparison. As originally and narrowly construed, a cost-benefit analysis of an intended policy alternative simply totaled the anticipated monetary costs of a particular project in one column, totaled its anticipated economic return (translated into monetary terms) in another column, and compared the two. The method was first used in the public sector by the Army Corps of Engineers in planning and justifying water projects during the 1930s.[4] Costs, in addition to those of construction, included, for example, losses to people whose land would be flooded. Benefits, in addition to hydroelectric power and increased irrigation capacity, included the creation of recreational facilities.

Many of the methodological problems involved in carrying out and interpreting such relatively narrow cost-benefit calculations have been studied by economists for many years, and most are now generally resolved. However, problems that are not completely methodological arise in trying to extend cost-benefit calculations to weigh intangibles whose monetary value is not easily established, as is the case with many important risks. One can, for example, compare anticipated monetary losses to the fishing industry in the Northeast due to acid rain to the costs involved in reducing industrial emissions that are the cause of acid rain. But it is far more difficult and, to some, morally repugnant to place a dollar value on serious injuries to human beings or on the loss of human life (NRC–Obs.; AAAS–5).[5]

Quantitative comparisons of risks and benefits also carry a burden of uncertainty in cases where both the risks and the benefits are anticipated in the future and, therefore, are more difficult to assess. At the extreme, those comparisons may involve risks and benefits to distant future generations who are likely to live under different circumstances and who may therefore also weigh risks and benefits differently than we do now (NRC–Obs.). Nuclear waste disposal represents the classical future generation problem (See Section II–E).

Finally, the risks and the benefits of a specific technology may not fall on the same groups in the present generation. The risks and costs of a synthetic fuels industry, for example, will fall most heavily on coal miners and on the population of Western States in the forms of environmental damage and loss of water for agriculture. On the other hand, heavily populated regions in other parts of the country could benefit greatly from the availability of synthetic fuels.

All of these uncertainties underline the fact that assessments of the risks, costs, and benefits of technological developments, and the policy decisions to be based on them, necessarily involve value judgments that cannot, therefore, be reduced entirely to scientific terms. However, formal analytical tools such as cost-benefit analysis can be of powerful assistance in displaying the likely consequences of different policies and in indicating which residual uncertainties can be reduced by better scientific information or analysis (*ASTR–II*).

If, as it seems likely, the science and technology enterprise will be called upon to a greater degree in the future to contribute its best possible insights about risks and their regulation to decisionmakers and policymakers, then the analytical tools for extrapolating assessments of hazards into the future, for weighing risks and benefits, and for determining public attitudes about various classes of risks will need to be refined, both to improve their usefulness to policymakers and to clarify their limits.[6] In seeking that refinement it should be emphasized again that significant risks, by their nature, are frequently associated with technologies, processes, or products that also carry significant anticipated benefits. Likewise, while the risks inherent in a particular product or process can be eliminated by selecting a very different alternative, that alternative will carry with it risks and benefits that may be of a different nature. Risks and benefits associated with the use of coal and nuclear fission provide important examples. Thus, analyses are needed not just for comparing the significant risks and benefits associated with particular products and processes, but also for comparing risks and benefits of entire classes of products and processes. Such large-scale assessments necessarily involve a broad spectrum of disciplinary expertise and institutional perspectives. Therefore, both the quality and the usefulness of such analyses might be improved by increasing the breadth of expertise within specific disciplines and developing multidisciplinary methods of analysis (AAAS–1; AAAS–5).

REFERENCES

1. National Science Foundation. *The Five-Year Outlook: Problems, Opportunities and Constraints in Science and Technology*. Washington, D.C.: U.S. Government Printing Office, May 1980. See Volume I, pp 31–33; Volume II, pp. 123–144 and 493–520.

2. "Federal Regulation." Executive Order #12291. February 17, 1981.

3. Ibid.

4. Michael S. Baram. *Regulation of Health, Safety, and Environmental Quality and the Use of Cost-Benefit Analysis*. Report to the Administrative Conference of the United States (unpublished). March 1979. See pp. 1–8.

5. Ibid. Despite these obvious problems, a number of regulatory agencies do place monetary values on human life for the purpose of making cost-benefit calculations.

6. National Science Foundation, op. cit. (Ref. 1). See, for example, Dorothy Nelkin. "Science, Technology and the Democratic Process," Volume II, pp. 483–492

II Functional Area Problems, Opportunities, and Constraints

A. Introduction

The previous chapter was concerned with the impacts that science and technology are likely to have on problems that transcend or cut across specific substantive fields or areas of application, and on the ways in which developments external to science and technology are likely to affect their conduct. This second chapter focuses on likely impacts of science and technology in specific areas of application, organized around nine functional categories. Each section considers the ways in which science and technology can contribute to the illumination and/or resolution of a selected group of problems of national significance, and points to the limitations on science and technology in making those contributions.

The specific problems, opportunities and constraints discussed in this chapter are derived from discussions in the source materials published in the companion volumes to this report. Other published reports, including particularly the first *Five-Year Outlook* and the first three *Annual Science and Technology Reports*, have also been drawn upon to provide additional factual information to amplify or to round out the detailed treatments in the *Source Volumes*. The source materials for this report include the multiple perspectives of practitioners of science and technology, the Federal agency programmatic managers of science and technology, and policy experts. The discussions, based heavily on those perspectives, are intended to provide a framework or basis for public discussion of the issues.

The discussions in each section are not intended to include all issues in the functional area, nor do they treat issues in great depth. More comprehensive and detailed treatments of problems, opportunities, and constraints within a functional area can be found in the *Source Volumes* (cited in parentheses in this chapter) or in the additional sources (cited in footnotes).

Even with this selectivity, some of the sections that follow discuss more needs and opportunities than could possibly be fulfilled or pursued. The setting of priorities among those opportunities and needs is a policy decision involving value judgments. Therefore, it cannot be based solely on scientific or technical criteria. The purpose of the sections is to present a selected list of current and emerging problems, opportunities, and constraints for science and technology within each functional area as a basis for selecting items for the policy agenda and for viewing alternative approaches to problems of national concern.

Although problems and opportunities are usually presented in this chapter under only one functional area heading, that does not mean that they are not linked importantly to other areas. In fact, many problems have aspects or ramifications that transcend functional area lines. For example, the Nation's water resources and their allocation are discussed specifically in the section on natural resources, but they are also critical issues for agriculture and for energy. In turn, issues related to our future energy resources pervade all functional areas. Linkages are noted, where possible, but each problem or opportunity is discussed in detail only once.

B. National Security*

Science and technology have altered drastically not only the nature and scale of armed conflict in this century, but also the very meaning of strategic war as an option to achieve national objectives. Thus, the strength and productivity of a nation's advanced technological capability have become major elements in any geopolitical calculation (AAAS-6).

Since 1967, total national investments for research and development, measured as a percentage of Gross National Product, have been consistently higher in the Soviet Union than in any other country in the world (*SI-78*). Dollar cost estimates for Soviet military research, development, testing, and evaluation (RDT&E) expenditures indicate that they have exceeded annual U.S. expenditures during each of the past 10 years, leading to an aggregate gap of about $90 billion, measured in 1982 dollars. Moreover, an increasing share of Soviet military outlays is being devoted to RDT&E. Despite this imbalance, the United States has maintained its leadership in most basic technologies, in large measure because of its leadership across a broad range of commercial technologies. But the Soviet Union has been closing the gap in certain key areas, including electro-optical sensors, guidance and navigation, hydroacoustic technology, optics, and propulsion.

Federal R&D funding patterns for national defense from 1971 to 1982 are shown in Figure 1. The significant increases in proposed obligations for 1981 and 1982 reflect the President's commitment to rebuild U.S. defense capabilities. Proposed budget obligations for defense-related R&D will continue to increase during the next 5 years.

Since the overall U.S. international position with respect to advanced technology has a direct bearing on national security, the R&D programs of the Department of Defense aim not only at the development of specific defense-related technologies, but also at the maintenance of broad-based, long-range R&D capabilities in the private sector in such key areas as electronics and materials. Thus, increasing Federal funds for defense-related R&D will support programs in universities and in private industry, as well as in the Department of Defense's own facilities.

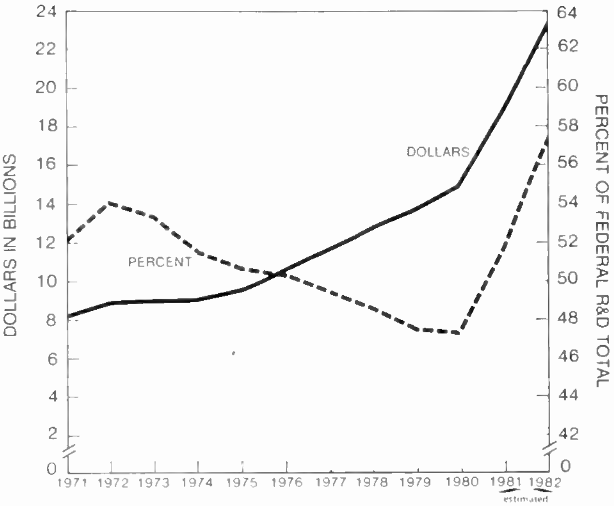

FIGURE 1. Federal R&D Funding for National Defense FY 1971-82. Sources: National Science Foundation and Office of Management and Budget.

Succeeding subsections provide brief descriptions of several programs likely to yield important results in the next 5 years in the areas of microelectronics, electronic systems, materials technology, aeronautics, space defense and surveillance, nuclear test detection, and human resources. Additional details about those programs, as well as anticipated advances in the development and testing of new conventional weapons systems, appear in the report of the interagency task group on national security in the *Source Volumes*. Speculations regarding aspects of national security that are not directly related to military systems also appear in the *Source Volumes* (AAAS-Obs.; AAAS-6; AAAS-11).

ELECTRONIC COMPONENTS

One area in which the United States maintains a clear technological advantage over the Soviet Union is in elec-

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*Unless otherwise noted, the material in this section is based upon the report submitted to the National Science Foundation by the interagency task group on national security that appears in the second of the accompanying *Source Volumes* tronics, particularly microelectronics. Rapid advances in that field have made possible the development of highly sophisticated sensors, some military applications of which are discussed later in this section.[1] Sensors based on microelectronic circuitry have also led to the development of "smart" integrated conventional systems, such as the Assault Breaker and Tank Breaker systems described in the *Source Volumes* (NS).

Microelectronics technology also underlies the rapidly advancing and converging fields of computers and communications; some military applications will be described below. Because sophisticated electronic circuitry underlies the entire U.S. defense mission, new demands are being placed on military personnel. Research in behavioral science aimed at understanding the complex interface between human beings and electronics systems is highlighted at the end of the section.

Given the centrality of microelectronics to the defense mission, the Department of Defense is focusing considerable attention on stimulating research and development at the frontiers of the field. The Very High Speed Integrated Circuits (VHSIC) Program, started during fiscal year 1980, is a 6-year, triservice/industry/university development program aimed at accelerating the advancement of microcircuit technology to firmly reestablish U.S. leadership in the field. The program also aims to ensure the continued industrial capability to provide the electronics required in the next generation of computers, missiles, radars, and intelligence processing centers. For the semiconductor industry, VHSIC is a substantial program, increasing the level of Department of Defense R&D support in integrated circuit technology to four times what it has been in recent years. The VHSIC program is designed to provide a substantial step forward in integrated circuit performance and production capabilities. A tenfold reduction in size, weight, power consumption, and failure rate, with accompanying savings in both initial and life-cycle costs of military computer processing systems compared with existing very large scale integrated circuit technology, is envisioned. New or improved computer chip architecture will be developed to permit chip design at an affordable cost, with minimum customization to reduce supply and logistic costs.

The Department of Defense has also recently initiated a very long range effort in Ultrasmall Electronics Research (USER) intended to advance electronics technology substantially beyond even the goals of the VHSIC program. With the advent of high-resolution electron, X-ray, molecular, and ion-beam lithographic techniques, an era of ultrasmall devices can be envisioned in which individual feature size might well be fabricated on the molecular scale of dimensions (i.e., 10-20 nanometers). In such devices, temporal and spatial scales would become so short and the electric fields so large that the physical concepts used in analysis of present day semiclassical device physics would be inappropriate and, indeed, might be misleading. Moreover, the new physical properties available could lead to radically new electronic device structures in that the individual device might assume a variety of functions that depend upon the influence of neighboring devices.

Thus, USER aims at revolutionary changes 10 to 20 years in the future that will depend upon entirely new concepts and materials. It will deal mainly with the physics, chemistry, metallurgy, and transport of charge in highly constrained geometrical structures that may be used in future generations of highly complex integrated circuits. USER has been called one of the last remaining frontiers of solid-state electronics, where the new fundamental unit is an aggregate or array of molecules or atoms. While this research program has highly speculative aspects, the potential payoff is very high in terms of U.S. preeminence in both military and civilian applications of electronics in the decades ahead.

ELECTRONIC SYSTEMS

COMPUTER SOFTWARE

Because advances in software technology have not kept pace with advances in computer hardware technology, the Department of Defense has recently begun a concerted attack on software problems, with special emphasis on a few high-payoff projects. The urgency of the software problem derives chiefly from the following factors:

(1) Software continues to be an increasingly important and expensive component of military systems, with estimates of Department of Defense computer software costs now running as high as $5 billion per year;
(2) Advances in computer hardware technology are rapidly altering computer system characteristics and expanding expectations for military systems;
(3) The Department of Defense has specialized software needs that are not shared with most commercial and industrial applications of computers; and
(4) The approaching completion of the Ada common programming language standardization effort provides an opportunity for coordinated development of generic software, with significantly reduced duplication of Department of Defense software support environments.

The software technology program has two major parts. The first is aimed at the short-term problems of realizing the potential benefits offered by the Ada common language effort. The second will be a longer term effort to greatly improve the effectiveness of automated software technology for military systems requirements and to complement the computer hardware of the mid-1980s.

ARTIFICIAL INTELLIGENCE

A state-of-the-art survey of the field of artificial intelligence appears in the accompanying *Source Volumes* (NRC-17). Coupled with work on automation and robotics, advances in the field are expected to play an increasingly important role in solving future military problems of engineering, management, logistics, reliability and maintainability, remote sensing, surveillance, and vehicle and weapons control.

A major Department of Defense research effort, scheduled to begin in fiscal year 1982, will investigate new techniques for automated systems that make use of state-of-the-art knowledge of artificial intelligence. The research will focus on methods for representing knowledge and for reasoning with knowledge in computer systems. Studies in systems automation will establish the foundation for a new generation of intelligent military systems, ranging from "expert consultants" to autonomous systems, that will provide new capabilities and ease manpower needs. The "expert consultant" systems will assist users in such tasks as planning and scheduling operations and diagnosing and repairing complex mechanical systems. Autonomous systems will be capable of commanding, controlling, and conducting military operations and will possess a capability to sense, think, and act.

The Department of Defense's work in robotics is closely associated with that research. Not only must the Department of Defense manufacture systems, it must support and maintain those systems across a farflung theater of operations, frequently in hostile operating environments, using a largely unskilled labor force with a high turnover rate. Thus, the demand for intelligent, flexible automation (robots) is obvious.

In the near future, the use of robots in Department of Defense systems manufacturing will increase in parallel with industry. Maintenance and repair activities at intermediate- and depot-levels will begin to use robots as the technology matures to the point where robot systems can deal with the complications and variations associated with such work. In the longer term, robots will be developed for field uses to assist combat and support forces; those applications will place still greater requirements on robots to be flexible and intelligent and to have sensory capabilities. It has been suggested, for example, that much onboard ship maintenance could be done more efficiently if each ship used a work cell operated by intelligent robots to manufacture parts needed rather than carrying vast numbers of seldom-used spares.

COMMAND, CONTROL, AND COMMUNICATIONS

Rapid advances in the converging fields of computer and communications technologies provide the potential to develop systems to improve the Nation's ability to coordinate its fighting forces around the world. Strategic command, control, and communications systems must be able to survive in combat and be highly dependable as the link between the command structure, strategic reserve forces, and troops in the field. Communications response time is also a critical factor. In pursuing the development and demonstration of computer/communications technology in a broad strategic and tactical systems context, experts are exploring computer communications technologies for application to both individual networks and internetwork systems. Advanced packet communications techniques and a powerful experimental internetwork are under development to provide local, regional, and long-band computer communications via ground radio transmission, terrestrial circuits, and satellites. Several experimental testbeds are being used to evaluate new information-processing technologies in realistic military environments.

The Department of Defense is also developing the technology for securing classified information processed or stored in computer and communications networks. Basic research in distributed computer systems is addressing the military need for geographically dispersed multicomputer command and control systems. In fiscal year 1981, new initiatives were begun on the design of secure distributed transition systems in which several security levels must be handled concurrently.

NEW MATERIALS TECHNOLOGIES

The availability of stronger, lighter, and more heat resistant materials that can be fabricated from domestically available raw materials is critical to the future development of military aircraft, spacecraft, and ballistic missiles. Over the years, pioneering developments in advanced materials that have emerged from Department of Defense programs have led to vastly improved military capabilities as well as the creation of new U.S. industries. Fiberglass-reinforced plastics, for example, are now familiar almost everywhere. The Department of Defense, through early developments in its science and technology program, has created the rapidly growing, new, worldwide industry of fiber-reinforced plastic composite materials. Commercial and private aircraft now in development will use increasing amounts of those materials to improve efficiency and reduce fuel consumption.

Although the achievements have been formidable, the pace of advances in military technology has imposed even more rigorous demands on systems performance, and the quest for materials with still greater performance capabilities must be pursued vigorously in the years ahead. Priority areas for research and development include improvements in carbon/carbon composites, in metal-matrix composites, and in rapid solidification technology.

The development of carbon fiber-reinforced carbon composite materials has led an increasing number of missile developers to consider those materials to achieve significant performance gains. Carbon fiber-reinforced plastics provide the very high strength and, especially, the stiffness needed for such applications as aircraft wing components, helicopter blades, and other highly loaded structures. Used in such applications, they can cut weights by 15-30 percent, greatly simplify design and construction, increase reliability, reduce production costs, and decrease fuel consumption.

Carbon fiber-reinforced carbon composite materials are also the most effective substances yet discovered for such extremely high temperature applications as ballistic missile reentry body nose tips and rocket nozzle throats. With further development, the materials are expected to become useful as high-temperature turbine blades for cruise missile engines. In addition to the performance gains possible with carbon/carbon composites, their domestic availability and potential low cost could make them attractive alternatives to high-cost gas turbine superalloys. Inasmuch as the superalloys contain substantial amounts of cobalt and chromium for which the United States is almost totally dependent on imports, the development of carbon/carbon composites as alternatives could relieve U.S. dependency on foreign sources.

Fiber-reinforced metallic materials, referred to as metal-matrix composites, have a variety of potential military applications, such as helicopter transmission housings, portable bridging components, strategic missiles, mines and torpedoes, tactical missiles, airframe and gas turbine components, and satellite components. In addition, the materials show promise in the future for such uses as laser mirrors, lightweight gun mounts, submarine propellers, and radar antennas.

One of the early results of the Department of Defense research and development program in metal-matrix composites is a fiber-reinforced lead grid material for submarine batteries that can lengthen the submarine battery replacement cycle from 5 to 10 years, thereby aligning it with the nuclear core replacement schedule and reducing maintenance costs appreciably. Another significant consequence of the work is the potential substitution of metal-matrix composites for such critical materials as chromium, cobalt, titanium, and beryllium. For example, it has been determined that composites consisting of high-modulus graphite fiber-reinforced magnesium alloys exhibit stiffness, strength, and dimensional stability equivalent or superior to beryllium at the same weight.

During fiscal year 1982, the Department of Defense will move vigorously into the area of rapid solidification technology. The objective of the new technology is to produce very high quality starting materials for new families of aluminum and titanium alloys and superalloys. Current modest investments have demonstrated sufficient promise and maturity of the technology to justify initiating a major, long-term financial commitment to accelerate the development of the new materials.

Rapid solidification technology involves solidifying metals and alloys from a molten state at a very fast rate, leading to the possibility of alloys with superior high-temperature strength, vastly improved corrosion resistance, and increased lifetime. For example, a new superalloy has been made that can run 100°C hotter in jet engines, thereby offering the design flexibility of either a 15 percent thrust increase or a dramatic reduction in fuel consumption. A new aluminum alloy has been developed that is 30 percent lighter for aircraft construction. In the future the new alloys could enable airplanes to either carry 30 percent more payload or decrease fuel consumption.

During the next 5 years the Department of Defense's rapid solidification technology program will involve basic research, exploratory development, specific technology demonstrations, and manufacturing technology efforts to be conducted at university, industrial, and government laboratories. The technology emerging from that thrust is expected to provide major economic benefits to transportation, space, and energy systems and to the U.S. commercial manufacturing base in general.

AERONAUTICAL TECHNOLOGY

The integration of advanced electronics and materials technologies is leading to significant improvements in the combat capability of tactical aircraft. It will soon be possible to maximize aircraft performance by automatically changing the shape of key aircraft components in flight such as wing sweep, airfoil camber, and engine inlets; to provide independent six-degree-of-freedom control to increase agility and minimize weapon delivery errors; and to integrate the flight, fire control and navigation systems. Those advances will provide task-tailored handling qualities. Fire control information will be used to automatically or semiautomatically assist the pilot in maneuvering the aircraft. Additionally, the new control concepts provide the capability to conduct a maneuvering approach to launch for air-to-ground weapons, thereby increasing survivability against ground defenses.

Recent investigations of the Department of Defense's aircraft engine development programs have concluded that additional efforts need to be placed on durability and reliability aspects during the early research and development phases of the program. The technology program is also being reoriented to stress reliability and maintainability. The increasing costs of propulsion systems and the supporting costs after they are placed in operation have become major concerns. Since a large cost factor is the number of parts in a propulsion system, current efforts are aimed at reducing the number of compressor stages by improving component performance. A major effort in the advanced turbine engine gas generator program is being made to increase the structural testing of promising new turbine engine concepts. Successful completion of those tests should provide a base for better transition of advanced technologies to engines on a timely basis.

A triservice working group has been formed to define an overall plan to develop and demonstrate small engine technology in the 1 to 7 pound per second airflow class. Those engines are applicable to auxiliary power units, light helicopters, light fixed-wing aircraft, and cruise missiles, all of which are widely used by U.S. armed forces.

SPACE DEFENSE AND SURVEILLANCE

The exploitation of space as a medium for important military functions raises the potential for hostile acts against U.S. space assets and presents the need to develop effective space defense and surveillance systems.

Recent advances in laser technology create possibilities for high-energy laser weapons for use in space. While very long lethal ranges and propagation at the speed of light make lasers uniquely capable for such applications, improvements by orders of magnitude in critical performance factors are required before weapons applications would be possible. The current Department of Defense effort is intended to develop the basic technology to apply those improvements to critical laser design parameters as well as advances in system performance.

In the past year, there has been substantial progress toward establishing the technology base for chemical laser weapons. Scale system testing has verified that the high fuel efficiency obtained previously with subscale systems also applies to higher power laser devices. In addition, researchers have developed unconventional concepts that equal, and in some cases exceed, the performance of existing devices. The high fuel efficiency and decreased weight attainable when the new concepts are applied could translate into a space laser weapons system of lighter weight or more fuel storage capacity if scaling continues to hold for very high power laser devices.

The Department of Defense's charged particle beam program is intended to demonstrate the feasibility of stable, predictable propagation of high-power, relativistic electron beams in the atmosphere over distances of military interest. The essential tool for investigation of atmospheric electron beam propagation is an Advanced Test Accelerator, now under construction at Lawrence Livermore Laboratory. The Experimental Test Accelerator, which will serve as its front end, was completed recently, and experiments will be performed in order to extend previous low-energy propagation data. When completed at the end of fiscal year 1982, the Advanced Test Accelerator may provide the essential scientific data required to begin planning preprototype weapons systems.

The principal emphasis in the space surveillance program has been on advanced visible and infrared detector arrays. The enhanced capabilities of such devices permit a variety of surveillance and battle management missions not possible previously. An advanced high-resolution infrared sensor has been installed in a National Aeronautics and Space Administration (NASA) U-2 aircraft to collect measurements of Earth background and tactical targets. Advanced detector array production for the Defense Advanced Research Projects Agency's (DARPA) TEAL RUBY experiment, the first on-orbit demonstration of advanced detector technology, will provide a target/background signature data base to support the design of future operational systems. The sensor is expected to be delivered to the U.S. Air Force for integration with the P80-1 spacecraft for a planned Shuttle launch later in this decade.

NUCLEAR TEST VERIFICATION

Research in nuclear arms tests verification is intended to provide a wider range of sensor options and greater assurance of detection and identification of nuclear tests. Current efforts involve the development of advanced sensor systems and associated data analysis procedures. With recent advances in characterization of seismic sources and wave propagation modeling, and the completion of a worldwide network of high-quality digital monitoring stations, it is now possible to develop source identification procedures based on physical and geometric properties.

A marine seismic system demonstration program will offer the possibility of monitoring, unobtrusively and at close distances, the most seismically active regions for clandestine underground tests. Such a system would provide significantly enhanced global monitoring capabilities of underground and underwater nuclear tests. It consists of a high-quality, three-component borehole seismometer and associated signal conditioning electronics suitable for long-term emplacement in the deep ocean floor. The program will demonstrate the feasibility of installing and operating a state-of-the-art seismic detector in a borehole in the deep (5.6 km) ocean floor. Application of the seismic data to detection, location, and identification of underground explosions will depend on analysis techniques developed under ongoing programs in seismic source and signal propagation theory and advanced data processing.

The marine seismic system program was initiated in late fiscal year 1979, and the design for the system was completed at the end of fiscal year 1980. Techniques and specialized equipment required for placing the instrument in boreholes in the ocean floor using the drillship *Glomar Challenger* have been completed. An at-sea test was conducted in the mid-Atlantic in early 1981 to verify operation of the equipment and to gather initial data on seismic noise reduction in that environment. The sensor, with associated electronics required for data acquisition and storage, will be developed by early 1982, and deployment of the system is scheduled for the summer of 1982. Full system communications will be added in 1983.

HUMAN RESOURCES

The availability of sufficient numbers of committed scientists and engineers is a prerequisite to the success of the defense-related R&D programs highlighted in this section. For that reason, current and anticipated future constraints on the supply of qualified engineers are of particular concern to the defense mission (Section I-B). The armed services are continuing to experience difficulties in recruiting and retaining qualified engineers, in part because of the high starting salaries available in private industry. For the same reason, university engineering departments, which may be called upon to conduct a wide range of defense-related research during the next 5 years, are unable to fill all available faculty positions.[2] Those problems could become increasingly severe during the decade.

More broadly, the rapid advances in science and technology that have increased the complexity of occupations and professions in the civilian sector during the past 20 years have brought about similar complexities in the defense sector. Weapons systems are more sophisticated, the speed of battle has increased, and the demands on the individual are mounting. Thus, a reasonable level of science and technology literacy is increasingly desirable, if not essential, for military personnel at all levels. In recognition of those circumstances, the Soviet Union has developed a curriculum in mathematics, science, and technology at the primary and secondary school levels, which is, on paper, the most advanced in the world.[3] In contrast, the degree of science and technology literacy of American high school graduates who are not intent on careers in science, engineering, or such related professions as medicine appears to have eroded seriously since the mid-1960s.[4]

Resolution of those problems involves a range of issues that go beyond science and technology. In any event, since the complexity of the defense mission is certain to increase, research is being pursued in several behavioral science fields with the objective of making the most effective use of the human resources available to the armed services. For example, it has become very costly to train people to operate and maintain high-technology weapons systems. Indeed, the cost of the training equipment often approaches the cost of the actual weapons system itself. Many of the skills needed for combat cannot be imparted using conventional techniques in a peacetime environment. For those reasons the Department of Defense conducts research in education aimed at the development of instructional systems, the identification and validation of candidate training media, and the assessment of output performance.

Current and evolving computer technologies are expected to influence the methods and effectiveness of personnel training. One result will be to make possible computer-based instruction systems capable of holding complicated conversations about a subject comparable to a Socratic dialog. By 1985, there should be several instructional systems of this type in daily use, and numerous efforts will be under way to expand the range of topics covered and the depth of understanding possessed by the systems. Also, by 1985, a knowledge representation scheme for aircraft maintenance data will be developed and demonstrated. It is anticipated that the system can be provided at reasonable cost and that it will be suitable both for training aircraft mechanics and for providing a diagnostic aid for special problems. Once the knowledge representation technology is demonstrated, it should be rapidly applied to a variety of other systems during the latter half of the decade.

Another major defense-related behavioral research program aims at enhancing the information-processing and decisionmaking capabilities of people working in demanding environments through better understanding of interactions between human operators and computers. In today's defense missions, sophisticated sensor and communications systems can gather an overwhelming amount of information that is valuable or critical to the conduct of operations. Better management of information must occur at the interface between machine presentation and human response in order to cope with the information load. Automation of more processing functions certainly can contribute to information handling, but even far into the future, effective and dependable system performance will still require effective human operators and decisionmakers.

Some problems that require attention in addressing the interface between machine presentation and human cognitive responses in the context of military operational environments and systems are:

(1) Dealing with potential information overload for operators and decisionmakers;
(2) Dealing with time-critical information;
(3) Deciding what information in a high-volume system to save or store;
(4) Finding the optimal organization for different mixes of information;
(5) Dealing with data bases prone to undetected errors or missing data;
(6) Presenting information in an optimal way for such diverse functions as alerting for a critical event, monitoring for an infrequent failure, diagnosing a problem condition, or presenting alternative courses of action; and
(7) Providing requisite control/input interfaces and employing effective feedback to users with varied skill and knowledge about the computer system.

Because these problems are interdisciplinary and at the frontier of interaction between the behavioral and informational sciences, there is a clear need to combine research from both the psychological and computer sciences. Research specialties that will be essential elements in such interdisciplinary projects include human factors, artificial intelligence, psycholinguistics, decision analysis, communications theory, information management, information display, human information processing, human aptitudes, systems engineering, and management science.

Human factors engineering, which is concerned with human performance implications for the design of hardware, provides a final example of a behavioral research effort supported by the Department of Defense. Research objectives are:

(1) To provide basic knowledge of the sensory, perceptual, cognitive, and response characteristics that underlie task performance capabilities;
(2) To translate task performance information into new ways to interface man with his equipment; and
(3) To develop methods for assessing man's contributions to systems.

Current research concentrates upon vision and visual perception characteristics, neurophysiological metrics (such as visual responses that indicate perceptual and cognitive processes), information-processing principles for man-computer interface design, decisionmaking in command and control, and workload measurement methodologies.

REFERENCES

1. See, for example, "Interview with Edward Teller," *Military Science and Technology*, Vol. 1, No. 1 (1980), pp. 38–47.
2. National Science Foundation and U.S. Department of Education. *Science and Engineering Education for the 1980s and Beyond*. Washington, D.C.: U.S. Government Printing Office, October 1980, pp. 24–31 and pp. 36–39.
3. Ibid., pp. 58–61.
4. Ibid., pp. 45–52.

C. Space

The exploration of space has only just begun. Yet a wide range of potential uses for space—for expanding knowledge about the planetary system and the universe as a whole, for solving problems on Earth, and for serving national defense needs—have already been identified. Reaping some of those potential benefits, however, may be far off, since space missions require extensive development programs and typically take several years from conception to launch. Even after missions are launched, they often need to be operative for several years before all the results are clearly evident. Additionally, deriving social, political, or economic benefits from those results requires that they be institutionalized into ongoing operational systems, and that, too, requires time. In that respect, the situation is not much different from that in other large-scale research and development programs, such as those in energy, transportation, and health. However, space exploration is still relatively novel, and our potential capabilities in that area are expanding rapidly. For these reasons we may still lack much of the experience required to formulate precise long-range plans that can make the most effective use of the potentials of space. In other words, we have to continue to invent the future as we proceed.

Space has been referred to as the new limitless ocean. Given the historic impulse to explore, to understand, and to control such uncharted regions, there is no doubt that humans will seek to master space. The only questions are: Who will explore space and reap its benefits? When will the various phases of exploration and mastery occur? The National Aeronautics and Space Act of 1958 and policy decisions by successive Administrations have committed the United States to leadership in space. Financial resources in this area, however, as in all others, are limited. Therefore, in order to ensure that the U.S. space program constitutes a logical, efficient, and cost-effective sequence of activities that can take advantage of emerging technological opportunities, space planning is carried out with a very long ranging time perspective. Because of the need for long-range planning, many of the activities discussed in this section, from the study of concepts to the employment of space systems, will not be completed for many years, even though they may already have been initiated or are well into the planning or development stages.

SPACE TECHNOLOGY AND SPACE SCIENCE

The U.S. space program of the 1960s concentrated on developing the technologies of propulsion, power, structures, controls, and electronics systems needed for space operations and on proving that space flight was not only technologically feasible, but also potentially very useful. The decade of the 1970s was a period of consolidation, initial development of a reusable space transportation system, and assessment of the most fruitful directions to pursue in space science, research, and applications. The directions selected supported application of space capabilities to the solution of terrestrial problems, and exploitation of the space environment for scientific purposes. Missions were continued and plans for future missions were initiated to exploit the unique capabilities of space systems to increase and deepen our understanding of the universe (NRC–9; SPACE).

Space activities in the 1980s are expected to be more international in character, more sophisticated in technology, and richer in their contribution to scientific knowledge. Results are expected that will be potentially valuable for commercial, civil, and military applications. Efforts will also be made to involve the private sector more in the support of U.S. space programs that could provide long-range commercial benefits. The communications industry has already made considerable commitments to space, and the promise of the unique environment it offers for certain manufacturing processes has received considerable attention. However, because it is often impossible to project accurately the benefits from a specific program, because space programs require such long leadtimes before benefits from investments are realized, and because benefits would likely be widely dispersed rather than centered in specific businesses, private enterprise has understandably not been inclined toward financial support of many major space programs. The private sector might be more willing to commit additional speculative funds to space programs if the payback period were shorter and profits guaranteed, and if it were more closely involved in long-range planning and could therefore influence directions of space programs to fulfill its future commercial needs. Therefore, for the near future, the Federal Government will remain the primary sponsor of the U.S. space R&D effort (SPACE).

One area of space activity in which the United States currently holds undisputed world leadership is space science. That area includes both interplanetary explorations and astronomical observations from orbiting satellites. Space exploration has paid huge dividends in other spheres by advancing technology for electronics in general, computer technology in particular, and many other scientific and technical areas. It has added significantly to knowledge about the universe and about how Earth and its inhabitants fit into the universe. Given that knowledge and the new capabilities provided by the Space Shuttle and the planned Space Telescope, this Nation is in a position to do even better work in the space sciences in the coming years (NRC–9; NRC–17; SPACE).

Investigation of the origin and evolution of the universe falls into four space science subcategories: astrophysics, solar-terrestrial physics, planetary research, and the life sciences (SPACE). Space science encompasses Earth, the solar system, our galaxy, and the entire universe. Its activities can provide information about the emergence of life on Earth and can investigate the possibility that life may exist elsewhere in the universe. It requires study of an incredibly diverse group of objects, such as diffuse clouds of gas and dust, stars and their systems of planets, comets, asteroids, pulsars, and quasars. And, until onsite measurements can be made, it must take into consideration radiation in all the frequency regions from visible light to cosmic rays. Detailed discussions of recent advances and promising opportunities in space science appear in the *Source Volumes* (NRC–9; NRC–17; SPACE).

It is worth noting, however, that although almost limitless opportunities exist for furthering our knowledge of the nature of the universe and our place in it, resource constraints will continue to require that explicit priorities be set. Scientific opportunities associated with a particular type of project must be balanced against opportunities lost by foregoing another project. As in other parts of the space program, selection of priorities cannot be made solely on the basis of what can be done or what, from a scientific perspective, should be done. There is no question that the human race will continue to explore the universe or that the United States will continue to be deeply involved in doing so. The important question, as already noted in a more general context, is: What specific opportunities ought to be seized and when?

THE SPACE TRANSPORTATION SYSTEM

The first successful orbital tests of the Space Shuttle in April 1981 launched a new era of U.S. space capability. The Shuttle Orbiter, which is the basic element of the Space Transportation System, is not only a reusable launch and reentry vehicle, but also a short-term, low-Earth-orbit space platform. Although the precise long-term launch rate to accommodate many of the potential payloads for the complete Space Transportation System continues to evolve, the Shuttle is now heavily booked for its early years of operation. Organizations already committed to its use include the National Aeronautics and Space Administration (NASA), the Department of Defense (DOD), other agencies of the U.S. Government, commercial concerns, and foreign governments (NS; SPACE). It may be, therefore, that if the realized traffic model grows significantly, the four orbiters already scheduled for production will eventually have to be augmented to realize the system's full potential. In addition, some planned payloads will require greater service facilities, more power, and longer stay-times in space than the current system can provide (NRC–9).

THE STATUS AND USES OF THE SYSTEM

The Space Transportation System is expected to replace, progressively through the 1980s, the expendable launch vehicles on which the space programs of this Nation and other nations have so far relied. It will consist of the Space Shuttle, the European-developed Spacelab, and upper stages for boosting payloads from the Shuttle's low-Earth orbit to higher orbits (NRC–9).

Full development and exploitation of the Shuttle system provide a wide range of exciting opportunities for the use of space. Several of those opportunities are expected to be realized during the next 5 years. For example, the Shuttle will be able to transport a wide variety of payloads as large as 15 feet in diameter and 60 feet long and weighing as much as 65,000 pounds. In addition, it can launch, service, and retrieve free-flying spacecraft. A Shuttle orbiter with a Spacelab mounted in its cargo bay will provide a low-Earth-orbit space platform with a stay-time in space of up to 7 days or longer. Because of the potential ease of carrying out some processes in the near-zero gravity environment of space, investigations in materials processing during the next 5 years are expected to lay the groundwork for the commercial production of new and superior materials in space (NRC–9). Also, the greater access to space provided by the Shuttle is expected to improve current capabilities for remote sensing of Earth and its environment. Satellites will be inserted into Earth orbit from the Shuttle, thereby lessening the need for expendable launch vehicles and easing limitations on the weight and size of payloads. It also is anticipated that the Shuttle will provide unique opportunities in infrared and optical solar astronomy. The launching of a life science laboratory is another possibility currently being examined (NRC–17; SPACE).

In addition to providing many new opportunities for studying and using the space environment, development of the Shuttle has been paralleled by the refinement of many technologies that will have potential uses in other arenas. For example, design of the Shuttle was accompanied by major advances in hypersonic aerodynamics, thermal protection devices, and very high pressure liquid-fueled engines. In addition, the Shuttle's flight control system, including the use of five identical computers for sensor computational redundancy, is an example of a state-of-the-art computer system offering improved and advanced control technology for many Earth-based applications (NRC–17).

SOME ANTICIPATED NEEDS FOR THE SYSTEM

Regular operational flights of the Shuttle are scheduled to begin in late 1982. They will mark the beginning of a new national capability, but not its maturity; additional refinements clearly will be needed. Since many of those needed refinements will become evident only as flight experience discloses them, some improvements in the system will have to be planned as the need for them is identified. One improvement already obvious involves the ability to transport heavier cargo loads into space. Another is a necessary augmentation in available electrical power, both to provide a supply adequate for expected payloads and to increase the Shuttle-Spacelab's stay-time in orbit. Current technology is sufficient for development of systems that could satisfy expected needs for the next 5 years. However, longer range needs suggest a requirement for increases in the capacity of energy storage devices and improvements in power-management systems (SPACE).

As mentioned, some future science and applications payloads will require greater stay-times in space than that provided by the augmented Shuttle-Spacelab. Mounting those payloads on unmanned space platforms in low-Earth orbits seems now to be the most efficient method of accommodation. Structures up to a certain size will be carried to space in the Shuttle's cargo bay, but larger structures will have to be transported in sections and/or prefolded and assembled in space. Some structures that may be needed in the future could be large enough to require fabrication in space. Therefore, work has begun in developing both the assembly and the fabricating techniques that would be needed and the technologies to be used to maintain the orientation and geometry of the structures (SPACE).

The period of rotation of any satellite is determined entirely by its distance from Earth's center. The rotation period of a satellite located approximately 24,000 miles from the Earth's center is 24 hours—the rotational period of the Earth itself. Since the positions of such satellites remain stationary with respect to Earth's surface, their orbits are referred to as geosynchronous. Communications satellites, for example, benefit greatly from being in geosynchronous orbit, and some remote sensing and space science tasks require that sensors occupy similar orbital positions. As space science and technology progress, the demand for the limited number of geosynchronous orbit positions is projected to grow rapidly, while the number of such positions obviously will not. Indeed, preemption of geosynchronous positions is an emerging international problem, as noted later in this section. Therefore, consideration currently is being given to collecting a range of payloads on large, unmanned geosynchronous platforms. Those platforms will pose special problems since they may initially have to be serviced remotely from great distances (SPACE).

The movement of space platforms from Shuttle altitude to geosynchronous orbit will require transfer vehicles having greater lifting capabilities than those of the Inertial Upper Stage and the Spinning Solid Upper Stages of the Space Transportation System currently being developed in coordination with NASA by the U.S. Air Force and industry, respectively. NASA is considering development of orbit transfer vehicles to meet those needs when they arise. The vehicles would also have the capability to place satellites in orbits that depart from the vicinity of Earth, and possibly to retrieve satellites both near to and remote from the Shuttle. The likely near-term (1990s) need is for an advanced propulsion system to serve as an upper stage for planetary missions in the space science program (SPACE).

Future advances in long-term manned space systems raise additional questions on how the human body functions in space. Neither the short-term nor the long-term effects of spaceflight on physiological functions are as yet adequately understood. Methods for mitigating potential adverse effects as well as advanced subsystems to provide life support for human operators are needed. Furthermore, optimal patterns of work, exercise, nutrition, and sleep must be worked out, and new procedures for maintaining health and treating illnesses in space will require development (SPACE). Thus, although the Space Transportation System opens a myriad of possibilities for the exploration of the potential of space, optimal use of the system will require many additional contributions from the science and technology enterprise.

REMOTE SENSING, COMMUNICATIONS, AND DATA MANAGEMENT

Sensing Earth and its environment from space provides information that can be obtained by no other known means. Thus, remote sensing is a singular resource which can contribute significantly to the acquisition of knowledge. Likewise, satellites in geosynchronous orbit have the unique capability of being in the direct line of sight of appreciable sections of the Earth's surface. They therefore offer unparalleled facility for receiving, processing, and transmitting information.

THE USES AND POTENTIALS OF REMOTE SENSING

Remote sensing from space can provide accurate and continuously updated information on Earth's resources and environment vital to the effectiveness of public policy decisions (SPACE; NR), as well as information useful in protecting our national security. Some remote sensing programs are already in operation, while others are in planning or development stages. Since 1972, the United States has conducted civil remote sensing for natural resources management and environmental monitoring through Landsat satellites. Those satellites provide information about both renewable and nonrenewable natural resources throughout the world, and their information is used by many other countries. The acquisition of those data has implications for the search for additional sources of such materials as scarce minerals and energy resources (*ASTR–III*).

Monitoring urban and suburban residential patterns is also possible through remote sensing. Another potentially useful application is in forecasting the production of all major crops (AGR; SPACE). Descriptions of additional applications appear in the *Source Volumes* (AGR; NS; NR; SPACE; NRC–9).

COMMUNICATIONS

The phenomenal growth in international and domestic communications satellite networks during the 1970s surpassed all projections and created a need for communications satellites with greatly enhanced capabilities (SPACE). That growth rate is expected to continue, particularly as some of the middle-tier countries implement their own systems and as other experimental applications, such as emergency and disaster communications and land-module voice communications, become operational (SPACE; IA). It should be noted that the development and use of communications satellites is one aspect of the national space effort where the private sector has been and will continue to be heavily involved.

The Tracking and Data Relay Satellite System currently under development is expected to become operational in 1984. It is designed to be able to handle increasingly higher rates of data transmission from Earth-orbiting satellites. However, no existing or planned system is expected to be able to handle the large data loads expected in the 1990s. For this reason, NASA is presently focusing research on developing, within a decade, a communications capacity that is several times as large as the current capacity and is based on a highly flexible wide-band data communications network. Aspects of this research and development program include opening up a new frequency band for satellite communications applications and developing advanced multibeam antennas and onboard switching systems to increase the capacity of presently used and planned frequency bands (SPACE).

DATA MANAGEMENT

Remote sensing and communications satellite capabilities are placing considerable stress on the ability to process and use data both effectively and cheaply. Thus, the field of data processing has emerged as a very important element in translating the potential of space into actual benefits. As a result of past technological developments, the end-to-end cost of processing satellite data has decreased substantially—from about $100 per processed megabit (in other words, per million pieces of binary information) to something on the order of $6 per processed megabit. If the current rate of decrease continues to 1990, the cost would be reduced to $1 per megabit. Even so, the annual cost of processing daily full-coverage data from an operational Earth-resources satellite could still be extremely high (SPACE). The problem of cost could hamper exploitation of the full potential of remote-sensing capabilities during the coming decades (SPACE; *ASTR–III).*

INTERNATIONAL COOPERATION AND COMPETITION

Since space projects are major, long-term undertakings, they provide attractive opportunities for international cooperation. The United States, as the world's leader in space, has taken the lead in implementing many of those opportunities. This country currently has a variety of cooperative space science programs with other nations. The largest and most complete cooperative space program is Spacelab, developed by 10 European countries under the management of the European Space Agency (ESA) according to design specifications arrived at jointly by NASA and ESA. NASA is also working with Canadian and French agencies to develop and demonstrate a satellite system that will locate ships and aircraft in distress by monitoring the emergency beacons they carry. The Soviets are developing a similar system and have agreed to make it compatible with the U.S./Canadian/French system. Cooperation between the United States and the U.S.S.R. in the life sciences has provided this country with some scientific information and some opportunities to fly experiments during the current hiatus in U.S.-manned flights (NRC–9; SPACE).

The International Sun-Earth Explorer (ISEE) also involves cooperation between NASA and the European Space Agency. In this project, which explores the workings at the boundaries of the Sun-Earth plasma, coordinated measurements of the magnetosphere are being made. A desirable future step in a comprehensive program of cooperative research on the structure of the magnetosphere and its interaction with the solar wind would involve measurements in the total Sun-Earth system from a minimum of four spacecraft (NRC–9).

The People's Republic of China (PRC) has entered the space era—successfully orbiting eight satellites and developing a launch vehicle to carry satellites into geosynchronous orbit—and opportunities for cooperation with that country in civil space activities are beginning to open up. Under a recently signed U.S./PRC agreement, PRC is considering the purchase of major Earth-observation equipment from U.S. industry (SPACE).

Civil space applications have also become a potential arena for competition between this country and several other industrialized countries that are rapidly developing their own capabilities. For example, Ariane, a predominantly French rocket, has been billed by some potential European users as a possible alternative to the Space Shuttle for delivering satellites into orbit. Although the development of Ariane is somewhat behind schedule, the long series of delays that plagued the Shuttle led the International Telecommunications Satellite Organization (Intelsat) to place orders for launching three satellites with Ariane instead of with the Shuttle.

Several less developed countries are already profiting from U.S. space activities, particularly in the communications and remote sensing areas. Planning is in process for the Second United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE), currently scheduled for 1982. The conference, the first since 1968, will focus on the practical benefits of space activities, particularly for the less developed countries (SPACE).

However, the "window from space" provided by remote sensing and communications satellites is by no means universally acclaimed. Indeed, the capabilities of those systems have led to demands—often strident—for a "new world information order" that could place severe limits on transborder information flow (AAAS–6). Communications satellites that can beam programs directly to home television receivers from distant locations are regarded by some countries as a violation of their national sovereignty. In addition, remote sensing capabilities are perceived as being, at worst, a new kind of economic espionage posing a threat to the exclusive control of a nation over its own national resources—a focus of colonial exploitation. At best, the capabilities of both communications and remote sensing satellites raise difficult questions about who holds proprietary rights to information, and those questions are bound to be hotly debated during the next 5 years (AAAS–6; IA).

A final source of potential friction that may, however, be easier to resolve is associated with the concern of several of the more scientifically advanced third world countries that they are being preempted from implementing satellite systems to serve their own domestic and regional needs. There are, of course, only a limited number of positions available for satellites in geosynchronous orbits, and at present a relatively limited frequency band available for satellite communications. Understandably, the less developed countries do not want to be completely dependent on the good will of the industrialized countries for their future communications needs, a situation that could easily occur if available geosynchronous orbits and frequency bands become rapidly saturated (SPACE; IA). On the other hand, it is likely that technological developments will greatly increase the information-handling capacity of an orbital slot, as well as the number of noninterfering slots, so that there may well be no shortage of channel capacity in the future.

The United States has entered an era of greatly enhanced capabilities for exploring and making use of the potential of space. But, as in so many other areas, the United States no longer enjoys undisputed dominance. Other industrialized countries have developed their own impressive, if still limited, capabilities. Many less developed countries now understand both the potential advantages and the potential threats of sophisticated space systems. The development of U.S. space policy through the 1980s and beyond will have to recognize increasingly the concerns of other countries, the common as well as the divergent interests among countries, the political and financial advantages to be gained from carefully selected cooperative ventures, and the potentially stimulating effects of international competition in civil applications.

D. Health

Since the beginning of this century, great progress has been made in improving the health status, quality of life, and life expectancy of people in the United States and throughout the world. Figure 2 shows changes in life expectancy in the United States since 1900. That progress has come about through advances in sanitation conditions and nutritional practices, through the control of such infectious diseases as smallpox, and through the early diagnosis of disease and other improvements in the health care delivery system. Moreover there are numerous indications of further advances yet to come. The new recombinant DNA technologies, for instance, are expected to aid the development of a wide variety of substances, including new and more effective vaccines and drugs, and perhaps will help in the control of genetic disorders. The discovery of interferon and its effects on the human organism holds promise for improvements in the treatment of viral infections and, maybe, cancer. Recent advances in the neurosciences—such as the discoveries of additional neurotransmitter substances and the naturally occurring painkillers, the endorphins—have improved our understanding of the functioning of the brain and may result in great progress in the treatment of mental disorders (NRC–2; NRC–14; NRC–17; HEALTH; *ASTR–III*). All of these advances can be linked directly to biomedical science and technology activities.

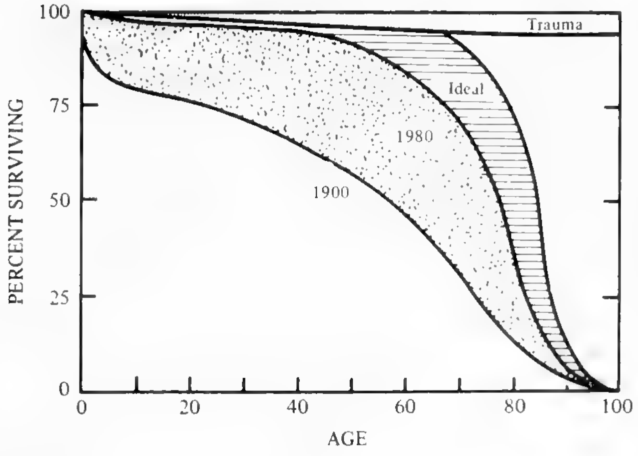

FIGURE 2. Survival of the American Population.

The curve for 1900 depicts the percentage of all people born before 1900 who in that year would have been 10, 20, 30, 40 years old, etc., and who, in fact, were alive in 1900. The curve for 1980 is constructed similarly. The "ideal" curve is a hypothetical extrapolation, with trauma (externally generated injury) the dominant cause of death in early life. Since 1900, life expectancy has increased significantly at all ages. Because of the remarkable increase in survival during early and middle years, the survival curve of Americans today need be improved relatively little to approximate the "ideal."

Source: James F. Fries, M.D. "Aging, Natural Death, and the Compression of Morbidity." *New England Journal of Medicine*, Vol. 303(1980), p. 131.

Some needed health improvements, however, depend heavily on lifestyle and on environmental changes, which advances in biomedical science and technology cannot effect alone. Such improvements will be facilitated by a broadened approach, merging biomedical, behavioral, and environmental considerations (NRC–2). There also appears to be an increasing need for the U.S. biomedical community to address diseases and conditions not typically considered problems for Americans. For example, there are many tropical diseases to which American military personnel are exposed that will require increasing attention in order to counteract the severe toll those diseases take on combat activities. Those diseases include malaria, scrub typhus, hepatitis, diarrheal disease, and arbovirus infections (NS). These diseases also pose serious problems for people in the developing countries with whom the United States will increasingly interact (AAAS–7). In addition, the further development of unconventional weapons will present new classes of injury, the treatment of which will require the development of new technologies (NS).

An overriding concern to Americans now and in the years ahead is the escalating cost of the health delivery system. Between 1967 and 1978, health costs, as measured by the Consumer Price Index (CPI), rose about 120 percent compared with 95 percent for the overall CPI. Although such other factors as labor costs need to be considered, one of the major mechanisms for slowing the escalating costs of the health care system may lie with health research advances. For example, new cost-efficient technologies can reduce the need for labor-intensive services and can suggest more appropriate ways to use outpatient ambulatory facilities, although, as discussed below, other technologies may raise health care costs. Advances in medical research may also reduce the use of costly surgical procedures and suggest less expensive forms of medical care. Furthermore, research into preventive approaches for some diseases could greatly reduce the need for costly primary health care services (NRC–2). Thus, although advances in biomedical research and development cannot control escalating health costs by themselves, they do present an opportunity for mitigating the problem in the coming years.

This section considers a range of high-priority health needs and opportunities requiring consideration during the next 5 years. They are (1) increasing emphasis on the prevention of disease; (2) dealing with a shifting age distribution in the American population; (3) dealing with such addictive behaviors as alcoholism, drug abuse, and cigarette smoking; (4) fostering the development and assessment of health care technologies; and (5) development of better and more cost-effective health care delivery systems. Some constraints on accomplishing these goals are considered at the end of the discussion.

FURTHERING THE PREVENTION OF ILLNESS

The contributions of basic biomedical research to the prevention and containment of many illnesses have been substantial. For example, while cardiovascular diseases remain the number one killer in this country, the rate of death from those illnesses has fallen by more than 30 percent since 1950. A variety of factors have played a part in the rapid advance against heart disease, including more effective drugs and procedures for repairing the heart and diseased blood vessels. One major factor in the declining mortality rate from cardiovascular disorders appears to be an increase in the use of preventive measures. Adult Americans are increasingly heeding warnings about the adverse effects of certain personal habits, such as cigarette smoking and high consumption of animal fats, although there is evidence that the smoking rate in adolescents is increasing. Americans are becoming more aware of the dangers from high blood pressure. Additionally, new and improved methods for treating hypertension, including new drugs that are more effective and have fewer side effects, are now being applied widely (NRC–2; NRC–14).

Cancer, the most feared of the life-threatening diseases, remains a major cause of death and debilitation in this country. Approximately one person in four now living in the United States will develop some form of cancer in his or her lifetime, and one in six will die from this broad class of diseases if present incidence and mortality rates remain the same. However, some 30-40 percent of all serious cancers are now being treated successfully, and there is reason to believe that that rate will continue to improve. In addition to treatment advances, there have been some marked advances in developing strategies for minimizing the risk of developing cancer. Known risk factors for cancer include a variety of environmental factors, such as tobacco smoke, radiation, and viruses, as well as such other factors as attitudinal variables, genetic predisposition, congenital defects, and aging (NRC–2).

Although great progress has been made in both the treatment and the prevention of illness, remaining high incidence and mortality rates indicate that additional progress is still badly needed. It is widely agreed that further progress in the treatment of disease will come primarily from additional basic biomedical research efforts into the causes and detailed courses of specific disorders (NRC–2; NRC–14; HEALTH). Those research efforts will have to continue if methods of treating illness are to be substantially improved in the coming years.

Major opportunities also appear to lie in illness prevention—although, of course, not all illness can be prevented— and a variety of suggestions for maximizing the probability of achieving those potential advances appears in the *Source Volumes* (NRC–2; SSRC–2; NS; HEALTH). Two related strategies meriting attention and action in the next 5 years are: (1) improving the research base linking behavior patterns and lifestyles with cancer, coronary, and other diseases; and (2) increasing efforts to motivate the public to adopt healthier lifestyles and behaviors.

IMPROVING THE RESEARCH BASE LINKING BEHAVIOR PATTERNS AND LIFESTYLES WITH CANCER, CORONARY, AND OTHER DISEASES

Many medical problems, including some of the most common in modern society, such as heart disease and cancer, appear to be influenced by social and behavioral factors. The processes linking behavior patterns to physical illness may be grouped into three broad categories: (1) direct psychophysiological effects, which involve changes in tissue function via physiological responses to such psychological and social inputs as stress; (2) habits and lifestyles that are damaging to health, such as cigarette smoking, excessive consumption of alcohol, and poor dietary patterns; and (3) reactions to illness and the sick role, which may lead to a delay in seeking medical care or a failure to comply with treatment and rehabilitation regimens (SSRC–2).

These categories include a broad range of factors generally acknowledged to be important in health and illness. However, convincing evidence about the specific causal relationship between risk factors and heart disease, cancer, and other major causes of illness is lacking. Therefore, research efforts need to progress beyond their current point of simply identifying correlations between psychosocial factors and physical illness toward the identification of those causal relationships. Accordingly, an important priority for scientific research will be to integrate behavioral and biomedical knowledge in a manner that identifies the factors underlying the interplay between behavior, pathological processes, and bodily dysfunction to provide a base from which truly effective treatment and prevention techniques might be developed (SSRC–2).

MOTIVATING THE PUBLIC TO ADOPT HEALTHIER LIFESTYLES AND BEHAVIOR PATTERNS

Although the evidence is not yet complete, there are ample indications that lifestyles and behavior patterns are critical elements in sustaining high levels of individual health (NRC–2; SSRC–2; HEALTH). A related problem for the health care enterprise then is: How can individuals be better motivated to adopt healthier lifestyles and behaviors?

Various approaches have been used in the past, most of which have taken the tactic of modifying or treating already established patterns of behavior. Some of them are (1) using social pressures and media campaigns to educate groups of people; (2) using individual treatment approaches, such as behavior therapy and hypnosis, that can condition individuals to change their deleterious lifestyles; and (3) using public health approaches aimed at labeling of dangerous products and warning the public in other ways of potential health hazards. Although these approaches have been moderately successful, a different kind of approach, one that attempts to dissuade people from adopting those deleterious behavior patterns in the first place, could also be productive. Development of those techniques, which might serve preventive rather than simply treatment functions, requires a shift in research focus toward acquiring a better understanding of the factors encouraging health-impairing habits, and not just a focus on techniques to modify them once they have been acquired (SSRC–2).

DEALING WITH A SHIFTING AGE DISTRIBUTION

There have been major changes in the demographic profile of the U.S. population over the past decades. The changes have stemmed both from a sharp increase in birth rates after 1947, with a sharper decline after 1957, and from increased lifespans for older Americans. Of particular importance to the health field are the changes in age and sex characteristics of the population. The number of persons aged 65 and above, for example, is now projected to increase by nearly 50 percent before the end of the 20th century. Marked differences in male and female mortality rates will also create different lifestyles and health needs for men and women. For example, under present conditions, a newborn American female can expect to live 9 years longer than a newborn male (NRC–1; NRC–2).

Continued changes in the age/sex profiles of the population will require both individual and societal flexibility in anticipating national health care needs. On the one hand, more people will be unwilling to retire at relatively early ages, since their capabilities for productive work are likely to remain high longer into their lifetimes. On the other hand, more people will have to be concerned with supporting and caring for an elderly parent, and the number of people in nursing homes and intermediary care facilities will increase. There also will be increased pressure on the working population to provide for the needs of the elderly (NRC–1). These changes will demand both individual and societal adjustments.

Changes in the age and sex profiles of the population have, similarly, placed new demands on science and technology to increase knowledge about the aging process and about health needs and health care appropriate for that population. Additional research emphasis on problems of aging people will be needed during the next 5 years to enable the United States both to deal with and to take full advantage of the potential in its aging population. Science and technology can affect problems associated with an aging population in many ways, two of which are discussed below. One is by increasing the functional capacities of the elderly, and the other is by assessing and redesigning health services to meet the needs of the aged more effectively.

INCREASING THE FUNCTIONAL CAPACITY OF THE ELDERLY

People reaching the age of 65 today are more educated, healthy, and economically secure than ever before, and their capacity for intellectual and physical performance continues to rise. However, in the face of the projected demographic changes noted above, the potential for even further development and expansion of the quality and productiveness of their lives needs to be further explored. That is partly due to a relative lack of knowledge about the true functional capabilities of that population, about their health care needs, and about the form of appropriate health services suited to sustaining longer, healthier, and more productive lives. Two kinds of factors will require particular attention if the functional capacity of the aged is to be increased. One set of factors is related to the debilitating effects of both disease and its treatment. For example, although some marked progress has been made in treating such disorders as arthritis, the senile dementias, diabetes, and atherosclerosis and other cardiovascular disorders, there is still a long way to go before the debilitating effects of those and other diseases are controlled. That will require continued and concerted research into the causes and courses of the diseases that afflict the elderly (NRC–Obs.; NRC–2; HEALTH).

There is also increasing evidence to show that in older people the body handles drugs differently than it does in younger people. Since the elderly often suffer from multiple chronic diseases and, therefore, follow complicated drug regimens, they are unusually susceptible to the untoward and debilitating effects of drug interactions. Therefore, additional information will be needed about drug metabolism and drug interactions in the elderly so that less debilitating and less dangerous drug regimens can be instituted.[1]

The second set of factors reducing the functional capacity of the elderly is concerned with social and behavioral patterns. Lifestyles and behavior patterns have long been suggested to affect longevity and health in later life. However, there is not yet a clear understanding of that relationship. In addition, there is increasing evidence that nursing practices can significantly affect the functional capacity of the elderly (SSRC–4). Furthermore, the social stresses to which the elderly are subjected, such as changes in family circumstances and in their economic status, can have major debilitating effects. Although some progress has been made in counteracting those stresses,[2] additional efforts will be needed in the coming years.

ASSESSING AND REDESIGNING HEALTH AND SOCIAL SERVICES TO ACCOMMODATE THE HEALTH NEEDS OF THE AGED

Public health workers and physicians agree that care of the elderly should be designed to maintain the functional and social independence of people as much as possible. Possible strategies for approaching that goal include (1) providing for better detection of emerging illnesses before they advance and the provision of assistance prior to the decline of functioning; (2) improving health care facilities to deter further institutionalization and enhance the ability of people to return to community living; and (3) increasing the availability of intensive services to treat and rehabilitate the elderly and chronically ill so that they may maintain the highest possible level of functioning (NRC–1; SSRC–4).

Science and technology can play an important role in all three strategies. Through improving methods for identifying high-risk cases and through preadmission certification services, alternative living and health care arrangements may be provided to limit unnecessary institutionalization. Through research advances, the quality of care provided in outpatient units, nursing homes, and intermediate care facilities may be enhanced. Similarly, advances in medicine are leading to higher quality and more appropriate care for the chronically and acutely ill. New drugs, for instance, may permit significant numbers of patients to be shifted from surgical to medical care and from institutions to community settings (SSRC–4).

DEALING WITH THE PROBLEMS OF ADDICTION

Substance abuse is one of the health problems causing greatest concern in recent years. Alcoholism, drug abuse, and cigarette smoking have all been related to both a wide variety of diseases and numerous social problems (HEALTH; *Outlook I*). For example, of all of the opportunities for preventing such diseases as cancer and arteriosclerosis, one of the most important is the reduction of cigarette smoking (*Outlook I*). However, while more than 30 million Americans have stopped smoking since the Surgeon General's Report, *Smoking and Health,* was published in 1964, there are still over 50 million smokers in the United States today (SSRC–2). Furthermore, smoking rates have been rising more rapidly among adolescents than in any other segment of the population, and, therefore, reduction in this habit must be a critical focus of efforts if we are to be successful at all in slowing the onset of life-threatening diseases.

Alcohol and drug-related addictions remain major problems for American society. Although there is no accurate estimate of the total incidence or prevalence of alcohol abuse, it has been estimated that over 10 million American adults are either alcoholics or problem drinkers. That is roughly 7 percent of the population 18 years of age or older. Although the number of heroin addicts is estimated to have dropped below one-half million by 1980, the abuse and misuse of most other psychoactive drugs appear to be rising. In economic terms, the costs of alcohol and drug abuse have been very high. They were estimated in 1975 at $43 billion for alcohol abuse and $10 billion for drug abuse, and they seem to have been escalating since then.[3] There are also the widely acknowledged social problems the addictive behaviors present.

Science and technology can help with the problems of addiction in a variety of general ways: by determining the neural and physiological bases of addiction and addictive behaviors, by increasing understanding of the barriers to changing behavior, by increasing understanding of the causal relationships between addictive behaviors and illness, and by better understanding the relationship between childrearing practices and the presence of addictive behaviors later in life (SSRC–2; HEALTH). Two frequently cited kinds of actions that can be taken to facilitate the application of scientific and technological advances to the problems of addictive behaviors are: (1) increasing the knowledge base about the causes of addictive behaviors, so that more effective prevention and treatment regimens can be developed; and (2) increasing efforts to translate basic behavioral research findings into biomedical practice (SSRC–2; HEALTH; *Outlook I*).

INCREASING THE KNOWLEDGE BASE ABOUT THE CAUSES OF ADDICTION

Any attempts to increase efforts either to prevent the development of or to control addiction once developed will have to be based on information about its causes.

Therefore, if substantial progress is to be made in the coming years in combating drug and substance abuse problems, increased research efforts into the causative factors will be needed. Much has already been learned in that area, and much is currently being studied. Major efforts are now under way concerned with cigarette smoking; those efforts should further our understanding of the physiological and psychological causes and basic mechanisms of nicotine dependence and withdrawal and should, therefore, increase the effectiveness of treatment of that public health problem. Studies also are ongoing or planned to understand better both the physiological and the psychological consequences of marijuana use in adolescents. Research on genetic predispositions and other biomedical factors appears to offer the first prospects for advancing knowledge of the causes of alcoholism (HEALTH). However, much additional research will be needed before ultimate solutions to addiction problems will emerge (HEALTH; SSRC–2).

INCREASING EFFORTS TO TRANSLATE BASIC BEHAVIORAL RESEARCH FINDINGS INTO BIOMEDICAL PRACTICE

The general problem of transferring basic scientific findings into practical use is discussed elsewhere in this report. However, there are some problems particular to behavioral approaches to the treatment of addictive behaviors that should be highlighted here, since the incorporation of behavioral treatments into practice has been at a slower pace than has been the acceptance of innovative biomedical advances. One reason for the slow pace of incorporation of behavioral approaches may be a lack of convincing evaluation data to document the effectiveness of the various innovative approaches. A second may be a simple lack of systematic communication between behavioral and biomedical scientists. Therefore, there is a need to determine more conclusively exactly which behavioral approaches are effective and which are not and, then, a need to improve the processes by which such information is disseminated to both health practitioners and the general public (SSRC–2).

FOSTERING THE DEVELOPMENT AND ASSESSMENT OF HEALTH CARE TECHNOLOGIES

As the size and significance of the Federal research effort have expanded, there has been increased concern about obtaining the greatest possible return from government-sponsored research. Of the $6.9 billion spent on health research in 1979, 62 percent, or $4.3 billion, was spent by Federal agencies, and, of that amount, approximately 80 percent was provided by the Department of Health and Human Services (HHS).[4] Recognizing that research and development frequently provide results that are useful beyond the original intent, there is a growing effort in Federal agencies to seek spinoff applications, to assess the relative benefits and costs of new technologies, and to disseminate technology created with Federal funding for use by others (*ASTR–II*).

A variety of problems and constraints associated with the use of new health technologies will have to be considered during the 1980s. For example, it obviously is impossible to implement all new technologies. Therefore, choices among the many opportunities and among various alternatives for achieving the same goal will have to be made. Questions must be asked about the costs, as well as the benefits, of those new technologies. Although many new technologies are cost-effective, others may not be. In addition, the high costs of certain technologies, such as the new scanning technologies, raise questions as to how those technologies might best be dispersed to serve the broadest possible range of patients. Finally, there may prove to be a need, in some cases, to control the rate of adoption of emerging technologies as their benefits and costs are carefully assessed. Decisions on those issues, like most policy decisions, are, of course, frequently based on more than scientific grounds (see Section I–E).

Prior to 1977, there was no formal mechanism at the Federal level for coordinating and conducting assessments of new or existing health care technologies, with the exception of the Food and Drug Administration's (FDA) programs related to pharmaceuticals. However, the assessment and dissemination of medical technology have accelerated rapidly in the last few years. For example, the Office of Medical Applications of Research (OMAR) was established in the National Institutes of Health (NIH) in 1977. OMAR, with the support of the National Library of Medicine (NLM), now serves as the focal point of a Federal-level strategy to assess the efficacy and safety of new health technologies and to aid the transfer of the results of those assessments to both practitioners and the general public (HEALTH: *ASTR–III*).

As an example of what has been done to achieve agreement about the efficacy of a new or emerging technology, OMAR emphasizes a process that involves the identification and selection of a broad range of health experts invited to participate in working groups. Broad and open participation is encouraged in the conduct of such assessments. Results from the assessments are then passed to the medical and scientific communities and to health planning and health delivery organizations (HEALTH). However, in spite of those programs and the progress made to date, several problems remain surrounding the development of strategies for transferring basic research knowledge into practice or technological development most effectively and, then, for assessing those new technologies. Science and technology efforts can be useful in both regards.

DISSEMINATING RESEARCH FINDINGS LEADING TO TECHNOLOGICAL ADOPTION

The dissemination of research findings with potential usefulness for the development of new and emerging technologies traditionally has not been well coordinated (See Section I–C). In the health area, increased Federal efforts have been begun during the past few years, under such auspices as the Lister Hill National Center for Biomedical Communications and the National Library of Medicine, to improve mechanisms for tranferring basic research knowledge into practice. Those are beginnings, but additional efforts will be needed to provide truly effective dissemination of such findings in the coming years (HEALTH).

An example of an innovative transfer mechanism in operation is the "Knowledge Base Program" at the Lister Hill Center. Through this computer-based program, knowledge is synthesized in a particular subject for use by a specified audience, such as those interested in a certain new technology. A prototype of the system, applied to the field of viral hepatitis, was established in 1977 and has been subsequently refined. Similar efforts might be initiated for the transfer of basic research knowledge in areas underlying application of emerging health technologies throughout the Federal and State Governments.

IMPROVING THE ASSESSMENT AND REGULATION OF NEW TECHNOLOGIES

With the advent of more and more sophisticated technologies to meet specific needs, the possibility of misuse also increases. In an effort to control the use of costly and, at times, inappropriate medical technology, various government regulations have been enacted to protect individuals and contain the costs of care. Federal regulatory activities, however, have often failed to give the regulators a clear mandate with workable goals (*Outlook I*). Furthermore, when billions of dollars hang on compliance decisions, intense controversy and delays are inevitable. There is a need, therefore, to improve the process of regulating health care technologies.

Scientific research can be useful both in assessing the costs and benefits of regulations and in curtailing or encouraging the use of new technologies (Section I–E). One problem in applying regulations with respect to costs is that current estimates are almost inevitably based on the costs of existing technology. Such estimates tend to overstate those costs. The longer range risks, too, are sometimes either under or over estimated. Through improved methods of cost projection and the use of an expanded base of experience, such estimates could be greatly refined (AAAS–5; see also Section I–E). Therefore, a greater effort is needed to improve the coordination of research findings in both the development and the control of health technologies over the next 5 years.

Increased efforts to assess the relative costs and benefits of new and emerging technologies also will be needed, both to ensure wider application of cost-efficient technologies by the private and public health sectors and to control the adoption of those technologies that are costly and only marginally effective. Many of the new technologies do promise to contribute to cost containment over time and to improve the quality of care offered Americans. However, only through careful assessment of the costs and benefits of those technologies can an effective policy for their adoption be developed (HEALTH).

ENSURING ADEQUATE AND APPROPRIATE HEALTH SERVICE DELIVERY TO ALL AMERICANS

Economic constraints make it especially important that available health resources be used as efficiently as possible. A key consideration in ensuring the availability of adequate and appropriate health services to all citizens continues to be the improved access to appropriate services for those persons who traditionally have been underserved. Among those groups are Black Americans, the Spanish-heritage population, Asian or Pacific Islanders, American Indians and Alaskan natives, rural Americans, the elderly, and low-income groups. While various population subsets have both unique attributes and certain common points regarding health status, some ethnic groups are generally not as healthy and do not live as long as do other groups of Americans.

Several alternate types of health care delivery systems that now exist, or are in the process of being developed, offer increased access and more appropriate health care to underserved populations. The most prevalent of those delivery services is the Health Maintenance Organization (HMO). As of 1978, 199 HMOs were providing health care to more than 7 million Americans. While there are various types of HMOs, the most predominant is the Prepaid Group Practice. Under that model, the families or individuals enrolled agree to pay a set monthly premium to the HMO, whether or not they need medical care. In many cases, the monthly premium is paid by the employer or by the government. The staff of the HMO is thus motivated, at least in theory, to keep people healthy and reduce unnecessary utilization of services.

Other health care programs aimed at underserved populations include community health centers, maternal and child health services, alcohol and drug abuse centers, and migrant health programs. In addition, the Indian Health Service provides a full range of preventive, primary medical, community health, and rehabilitative services to

Indians and Alaskan natives living on reservations. The network includes 51 hospitals, 99 health centers, and more than 300 health stations and satellite field health clinics.[5]

There is a need for systematic evaluations of existing programs over the next 5 years to provide a basis for adapting or redesigning health care services to meet the needs of all Americans. It is necessary to know if participants in government-sponsored programs receive health care equal to that received by other Americans, and whether health service agencies can be modified to provide for preventive health services to participants. Assessments of the relative merits of various delivery models for the provision of care to selected populations are also needed.

CONSTRAINTS ON ADVANCES IN THE HEALTH AREA

The preceding discussion and those in the appended *Source Volumes* highlight a large number of current and emerging opportunities for science and technology to have significant positive impacts on national health problems. The ability of the science and technology enterprise to exploit fully those opportunities will depend on a number of policy decisions to be made in the next few years. Most of the issues about which those decisions will have to be made are generic to all areas of science and technology; they concern such factors as financial resources, instrumentation, and information transfer. Two types of constraints on exploiting opportunities for improving the health of the American public are worth mentioning explicitly: (1) human resource limitations, and (2) effects of regulations on biomedical research.

In the case of human resource limitations, there remains the perennial problem of the geographic distribution of physicians. Additionally, there currently is a decrease in the number of young physicians entering careers in academic medicine, which will present problems in the longer term. Whereas, in the past, more than one third of medical students aspired to a career as clinician-teacher-investigator, that fraction has now diminished significantly. It is evident in terms of both the number of vacancies on medical school faculties and the number of applications for research support received by government agencies from persons with M.D. degrees. Although the causes of that trend are not well understood, it has serious implications.[6] Much of the progress in medicine during the past decade has come from academic physicians. Therefore, reversing that trend will be an important priority for the coming years if we are to realize the full potential for improved health presented by scientific and technological activities (NRC–Obs.).

Federal regulations impose a second major constraint on health-related scientific and technological activities. Whereas in many cases regulations are imposed on the products of research and development, regulations in the health area are frequently imposed on the scientific activities themselves (Section I–E). There is no disagreement that some control should be placed on health-related science and technology activities. Clearly, no individual should be subjected to undue harm, whether physical or psychological, as a result of biomedical research, whatever the potential benefits to be derived by society. However, applying those regulations in specific cases to determine, for example, what constitutes undue harm, or undue harm relative to a certain anticipated benefit, is often exceedingly difficult. Moreover, there is a growing belief that some regulations of biomedical research have been unduly restrictive and have unnecessarily hampered health-related scientific and technological progress. That concern, and the discussion surrounding it, led to revisions in the guidelines for recombinant DNA research in November 1980 and to revisions in the regulations for the protection of human and animal subjects in research supported by the Department of Health and Human Services in January 1981. Continued discussion and evaluation of the regulations controlling those research activities will be needed to ensure maximal use of the potential from biomedical research in the coming years.

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E. Energy

The United States developed economically in an environment that included secure, readily available, and relatively inexpensive energy supplies. With the petroleum embargo of 1973 and the subsequent rapid increase in the cost of imported petroleum, there has been a growing national awareness of the economic and national security implications of our dependence upon imported energy supplies. In the first few years after 1973, U.S. energy policy focused heavily on Federal intervention in the market and attempted to protect U.S. consumers from the reality of world petroleum prices. One adverse consequence of this policy was to discourage the long-term private sector investments in research and development necessary to increase domestic petroleum and natural gas production and to develop viable alternative energy sources that will inevitably be needed when world petroleum production begins to decline.

This Administration's energy policy is an integral part of the President's comprehensive Program for Economic Recovery. It is based on the conviction that, with regard to the development of energy sources, the collective judgment of properly motivated technical innovators, businessmen, and consumers is generally superior to any form of centralized programming. Hence, Federal investments will be made only in long-term research with high risks and potentially high payoffs. In general, the Federal Government will no longer assume responsibility for accelerating the development of newer technologies. Additionally, public funds will not be used to subsidize domestic energy production or conservation on the grounds that such actions lead to little additional security, and, on the contrary, divert capital, workers, and initiative from uses that contribute more to society and to the economy. Hence, this policy is designed to meet the challenge of providing a healthy economic and policy environment in which rational energy production and consumption decisions can be made that reflect the true value of the Nation's resources.

The power of the free market in alleviating short-term energy shortages is suggested by the fact that the growth in energy consumption in the United States, and of oil and transportation fuels in particular, is moderating significantly as conservation measures brought on by higher prices begin to take effect (Figure 3). Worldwide moderation in petroleum demand has also led to a glut on the international market and thus to a temporary stabilization of crude oil prices.

Forecasts of energy demand growth vary considerably, depending on economic and technological assumptions, on the assumed mix of future energy sources, and on projected price trends. Significantly, however, most recent forecasts project considerably smaller growth in U.S. energy consumption than earlier forecasts.[1] In particular, forecasts released by the Department of Energy (DOE) early in 1981 predict that U.S. energy consumption will increase at only slightly more than 1 percent per year from 1979 to 1990, well below the 2 percent growth rate forecast in 1979 (Figure 4). Petroleum, which provided 43 percent of U.S. energy needs in 1979, would provide only 35 percent by 1990. Coal use would increase from 19 to 27 percent of total energy use, with smaller increases in nuclear power and renewable resources. By 1990, conservation would permit overall energy use in the residential and commercial sectors to remain at about their present levels. Additionally, the use of energy for transportation is expected to decline significantly by 1990, permitting appreciable increases in energy use—and thus substantially increased economic activity—in an increasingly energy-efficient industrial sector (ENERGY).

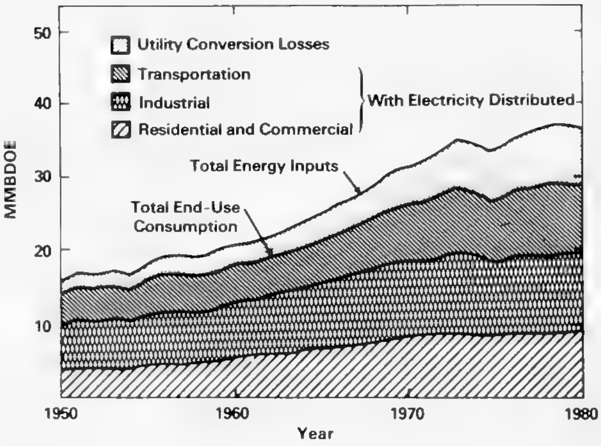

FIGURE 3. Consumption of Energy by End-Use Sector 1950–1980. Source: DOE, Notice of Public Hearings and Staff Working Papers: Public Discussion Package for the Third National Energy Plan, DOE/PE-0022. March, 1981

In short, the United States has already started to experience a major transition away from the use of readily exploitable, but depletable energy sources. The moderated demand for energy should provide sufficient time to resolve the longer term problem of assuring that adequate energy supplies are available in the future when petroleum supplies throughout the world are so far depleted and, thus, so costly that they can at best satisfy an insignificant fraction of the U.S.—and world—energy demand.

Some analysts believe that world petroleum production has already reached its highest levels, though others disagree. There is, however, reasonable consensus that world production will almost certainly plateau if not peak by the year 2000. By that time, demand for petroleum elsewhere than in the United States—particularly among the middle-tier countries of the third world—is expected to have risen sharply, resulting in increased competition and higher

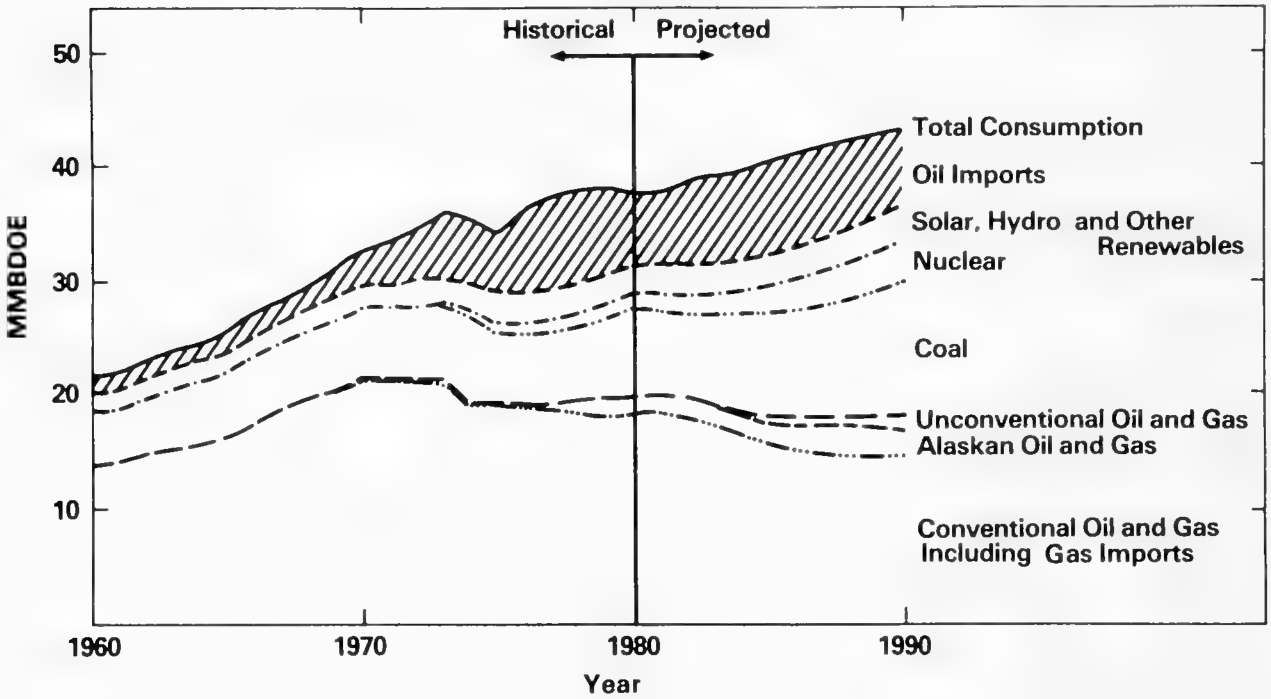

FIGURE 4. U.S. Energy Production and Consumption to 1990 (Best Estimate Case).

Source: DOE, Notice of Public Hearings and Staff Working Papers: Public Discussion Package for the Third National Energy Plan, DOE/PE-0022. March, 1981.

prices for supplies that are at best stable.[2] Thus by the turn of the century, liquid fuels used in the United States will most likely have to be derived from domestically produced petroleum; unconventional reserves of hydrocarbons (i.e., compounds of carbons and hydrogen) such as oil shale, heavy oils, and tar sands; and fuels made from coal and, to a lesser extent, from peat and agricultural products (NRC–15). Since liquid fuels from all these sources will be costly, their use will by then have to be restricted primarily to the transportation sector and to a few other situations where economic or environmental considerations make the use of alternatives impractical (ENERGY). Sometime during the 21st century, when petroleum and (later) natural gas are no longer available at any price, the United States will have to begin to rely almost completely on some mix of unconventional hydrocarbons, coal, nuclear fuels and renewable sources—principally direct solar energy—to satisfy its energy needs.

The mix of energy sources used in the United States during near and more distant future decades and the percentage that each source contributes to total energy consumption will depend on a number of related factors, including domestic and international demand, availability of conventional and unconventional hydrocarbons, relative end-use prices of various available alternatives, and, of course, available technology. Considerable technological development will continue to be needed to exploit available energy options even in the near-term future, and a good deal of scientific research that will be needed as a basis for those developments has yet to be carried out. Thus, the public and the private sector have initiated a range of scientific and technological programs aimed at helping to ensure adequate energy supplies in the future (ENERGY).

Some analysts believe that the few years during which a large Federal energy effort has existed have seen a marked shift away from the long-term scientific research needed to undergird future developments toward short-term results that could lead to rapid and, perhaps, premature commercialization. Given uncertainties about the types and mix of energy sources that will be economically and technologically viable in the distant future, the desirability of conducting research aimed at a wide range of possible high-payoff alternatives is almost self evident. Otherwise, the United States could become locked into relying on a narrow set of options that could ultimately prove not to be viable. For this reason, Federal support during the next 5 years will focus on truly long-term, potentially high-payoff scientific research (ENERGY).

The situation regarding advanced development is considerably different than for long-range research. In the past the Federal Government subsidized a wide range of technological developments. The Reagan Administration's policy proceeds from the assumption that the market is best suited to sort out most development options, and that Federal support should be limited to those potentially high-payoff options where the private sector is as yet unable to invest sufficient development funds. Thus, many potentially promising programs that previously received Federal subsidies have been curtailed or discontinued, and additional reductions in Federal development support during the next 5 years are likely (NRC–14; ENERGY).

Some of the major contributions that energy-related science and technology programs in the public and private sectors are expected to make during the next 5 years, and some of the problems associated with those programs, are highlighted below.

OIL AND NATURAL GAS PRODUCTION

Until economically competitive fuel sources are developed to supplement declining domestic reserves, exploration for new petroleum and natural gas resources accessible to the United States and the development of methods to enhance the recovery of oil and gas from known sources must be pursued. Administration actions to decontrol oil prices and to stimulate the investment climate through regulatory and tax reforms are expected to provide the necessary market conditions for these activities (ENERGY).

PETROLEUM PRODUCTION

Petroleum production in the United States has recently stabilized. If the United States were to sustain present levels of oil production, approximately 4 billion additional barrels would have to be located annually. However, there was only one year since 1950 during which more than 3 billion barrels of reserves were discovered. There is considerable disagreement about the probability of discovering new large or giant oil fields, but little disagreement about the fact that if such basins exist they are most likely to be in locations with harsh environments that will make exploration and commercial development difficult and expensive. For example, although the Outer Continental Shelf in the Alaskan north slope is a key location where large fields are being sought, environmental concerns and operating difficulties have slowed exploration and development and raised costs. Ocean beds also constitute another important potential source of petroleum. During the next 5 years, industry is expected to improve the technology for offshore exploration and drilling operations to minimize the chances for spillages, blowouts, loss-of-well control, fires, or other occurrences that may damage the environment or endanger life (ENERGY).

Advanced enhanced recovery techniques could lead to increased commercial production of petroleum from known domestic reserves. While the technological mechanisms of several enhanced recovery techniques are well understood, it is as yet difficult to predict whether they will be workable or profitable in any given reservoir. During the next 5 years, field tests, supported by laboratory investigations, will be carried out by industry in an attempt to improve these techniques. These tests should also permit a better assessment of both the economics and the environmental impacts of enhanced recovery (ENERGY).

NATURAL GAS

The Department of Energy estimates that domestic levels of natural gas from known, presently proven sources in the lower 48 States can be maintained only through the present decade. Deep well recovery could, however, sustain production levels well beyond that date. The prospects for discovering new reserves and exploiting known, unconventional reserves of domestic natural gas are considered good, and supplies from the lower 48 States can be augmented by Alaskan, Canadian, and Mexican reserves. Thus, while available and potential natural gas supplies are finite, they are not likely to be depleted as rapidly as oil—and could therefore serve as a substitute in some applications (ENERGY).

Since considerable natural gas reserves exist outside of North America, means for facilitating transoceanic shipment are also being studied. One possibility under active consideration would be to convert natural gas to methanol, which remains a liquid under normal temperatures and pressures. Another somewhat more controversial option would be to transport natural gas as a compressed, refrigerated liquid. Unfortunately, liquefied natural gas is highly flammable. The Department of Transportation has recently issued safety regulations for the transportation of liquefied natural gas that could mitigate this safety problem. However, the commercial feasibility of importing natural gas in any form is likely to depend primarily upon pricing decisions made by exporting countries (ENERGY).

UNCONVENTIONAL SOURCES OF OIL

Although the world's economically recoverable sources of petroleum are being depleted, the existence of vast unconventional sources has been known for some time, and more of these sources might well be discovered. Presently identified unconventional sources include giant deposits of heavy oils and tar sands in Canada, Venezuela, and in the U.S.S.R., and somewhat smaller though still considerable heavy oil and tar sand deposits in the United States and Madagascar. These deposits have not been exploited because the price of petroleum has heretofore precluded making the large investments required to mine and produce usable fuels from them. For the same reason, systematic exploration for other similar deposits has proceeded slowly. During the past few years, an effort to commercialize production from the Canadian deposits has begun. Given projected increases in the price of petroleum, some experts believe that fuels derived from these unconventional sources could begin to penetrate the market in the early 1990s.[3]

Oil shale appears to be the most promising unconventional source for the United States in the next decades, primarily because plans to proceed with commercialized mining and production have already been announced. Virtually all the readily exploitable U.S. oil shale deposits are located in the Green River formation in a small area at the juncture of Colorado, Utah, and Wyoming. Commercial exploitation of shale resources located in Tennessee and Kentucky is more problematic.

When heated to a sufficiently high temperature, well over 50 percent of the organic material from the Green River shales is recoverable as crude oil or gas. The resultant hydrocarbon-containing material can then be processed to remove residual sulfur, nitrogen, and arsenic compounds and upgraded slightly to serve as a source from which more traditional liquid fuels can be refined. All phases of the process from mining through the production of upgraded crude oil have been carried through the large pilot plant stage, and current economics suggest commercial viability of existing first generation processes. Mining and the disposal of solids represent a major fraction of the cost of extracting oil from shale, and are also sources of environmental problems. Additionally, water required for mining, production, upgrading, and revegetation of surface mined areas could severely limit production capacities. However, process improvements in second- and third-generation commercial operations that can enhance production efficiencies, reduce environmental problems, and use water more effectively seem possible (NRC–15).

COAL AND COAL DERIVATIVES

There is widespread (though not quite universal) agreement that for the remainder of the century there are only three available alternatives to burning petroleum products and natural gas to provide significant amounts of energy: (1) burning fuels derived from unconventional hydrocarbons, (2) burning coal or synthetic fuels made from coal, and (3) producing electricity and (perhaps) industrial process heat from nuclear fission. Liquid fuels produced from peat and plant products could provide a significant supplement in some limited applications—in agriculture, for example. Other alternative energy sources—direct solar production of electricity, advanced nuclear fission and fusion systems—may be options for the longer term future. Hydro, geothermal, wind, and ocean thermal sources could also provide limited though useful supplements in some parts of the country.[4]

DIRECT COAL USE

The United States has vast known coal resources that compose approximately 30 percent of the world's total, with the overwhelming bulk of remaining known world reserves located in Australia, the Soviet Union, and the People's Republic of China. Coal was once the preferred fuel source in this country, and at one time was used to produce 45 percent of its electricity. However, during the 1940s, economic, environmental safety, transportation, extraction and processing advantages of petroleum and natural gas led to its replacement. All of these factors, with the exception of the direct economic factor, still present significant obstacles to the expanded use of coal—either its direct use as a source of electricity or industrial process heat, or its use as the basis for a synthetic fuels industry. Because of these constraints, present capabilities for mining and burning coal are not being used to full capacity, a fact that has kept down the price of coal and worked as a disincentive to its further exploitation.[5] Even though coal use is expected to expand considerably beginning about the middle of this decade, production capabilities are not expected to be used fully until the 1990s (NRC–15; ENERGY; *ASTR-II; ASTR-III*).

While the country's coal reserves are vast, not all of it can be strip mined, and there are various health and safety problems associated with underground mining. It should be possible to reduce these risks by the continued introduction of new technologies such as longwall mining. These technologies can also improve the efficiency of coal extraction. Meanwhile, research that should provide a better understanding about lung diseases common among miners is being pursued. Ultimately, this research should lead to improvements in prevention and cure, though no drastic advances are anticipated during the next 5 years (ENERGY). While many experts believe that health and safety risks to miners can be reduced substantially, few, if any, would claim that they can be eliminated completely. For this reason, promising automated underground mining technologies that are also being developed in the United Kingdom and West Germany are viewed with increased interest by the U.S. coal industry and could begin to receive major tests in this country during the next 5 years (NRC–14).

Environmental problems associated with coal include damage to land from strip mining (particularly in the semi-arid Western States where a great deal of U.S. supplies are located), solid waste disposal problems, water availability, and atmospheric pollution from burning coal and from processes for its conversion to synthetic fuels. Efforts to deal with some of these problems are highlighted in Section II-G.

Conversion from oil and natural gas to coal as a source of electricity or industrial process heat would be facilitated by technologies that burn coal more efficiently and leave behind fewer solid and gaseous wastes. Fluidized-bed combustion, in which coal mixed with limestone (to absorb sulfur) is burned while being suspended by compressed air above the floor of the furnace, is practically a commercial option today. In this process coal is burned at a substantially lower temperature than in conventional combustion systems, thus reducing considerably the emission of oxides of nitrogen. Promising research into the physical and chemical processes occurring in coal combustion should permit considerable improvements in the fluidized-bed process after commercialization. Research of this type is also expected to facilitate the development and commercialization of other advanced coal burning systems (ENERGY).

SYNTHETIC FUELS

The capitalization costs for new synthetic fuels industries will be enormous. Thus, the rate at which synthetic fuel production from coal penetrates the market will depend critically upon the projected prices for alternative and gaseous liquid fuels—i.e., natural gas, petroleum derivatives, and fuels from heavy oils, tar sands, and shales. Sometime during the late 1980s, as processes for converting coal into gaseous and liquid fuels are commercialized, coal in these forms may begin to replace oil and natural gas in many applications.

The need for synthetic fuels made from coal has been felt in the past. Production of coal gas by reaction with steam became important in Europe and the United States after 1861. Germany built a number of coal liquefaction plants before World War II, and small-scale coal liquefaction feasibility studies were carried out in the United States during the 1930s and, again, in the late 1940s. The discovery of new, easily exploitable reserves of natural gas and petroleum, with consequent price reductions for the fuels derived from them, precluded large-scale development of these pilot synthetic fuels efforts. But they provided a scientific and technological base for further development. If there were no economic or environmental constraints, the United States could produce enough synthetic fuels to eliminate almost all imports, slow the consumption of domestic oil, and develop a substantial synthetic fuel export trade. Indeed, the availability of these fuels would be a crucial factor in helping Western Europe and Japan reduce their own petroleum imports. However, there are financial and environmental constraints, and science and technology will have to provide means for overcoming them. A primary need during the present decade is to learn more about different processes for producing synthetic fuels and about how to use different types of synthetic fuels in a variety of applications so that a range of viable alternatives will be available when large-scale commercialization becomes feasible (NRC–15).

The basic chemistry that underlies synthetic fuel production from coal is relatively simple. Coals are composed primarily of carbon and hydrogen, with smaller amounts of oxygen and other inorganic elements, depending on the type of coal. A number of chemical reactions occur when coal is raised to a sufficiently high temperature, including reactions that produce gaseous and liquid hydrocarbons (carbon-hydrogen compounds) that are usable as fuels. However, straightforward heating of coal also yields (in addition to solid char) a wide range of other gaseous and liquid compounds, most of which have too low a ratio of carbon to hydrogen to serve as good fuels. Efficient production of crude gases or liquids from which usable synthetic fuels can be refined requires, therefore, that additional hydrogen be available in the process. This hydrogen can be supplied in its pure, gaseous form. Alternatively, hydrogen can be extracted from water in the production process, in which case compounds containing oxygen as well as hydrocarbon compounds are produced. The same basic processes can be used to make synthetic fuels from peat or wood.

Commercially demonstrated processes are now available for producing usable synthetic gas from coal, and planned research and development efforts should demonstrate, within the next 5 years, improved process in terms of efficiency, reliability, and environmental acceptability (NRC–15; ENERGY). The first step in all these processes is to combine coal with steam (as a source of hydrogen) and either pure oxygen or air to yield a mixture of carbon monoxide, hydrogen, small amounts of methane, nitrogen (if air is used instead of oxygen) and some other contaminants—primarily compounds of nitrogen and sulfur. If the nitrogen and contaminants are removed, the resultant gas can be used directly as a fuel. Since the heating value of this gas is considerably less than that of natural gas and its transportation costs higher, its use for such purposes is expected to be limited. Gasified coal is, however, expected to be important for other applications: as a source of hydrogen for coal liquefaction; for conversion to methane (equivalent to natural gas); for the production of alcohol, particularly methanol; and, perhaps, for synthesis into gasoline and diesel fuel, and as a source of petrochemical feedstocks. Since conversion of coal to such usable end products by means of gasification involves multiple steps, efficiency can be increased considerably by carrying out several steps at the same vessel. Increased efficiencies of this sort appear to be possible. Their implementation will depend to a large degree on the markets for the output of first-generation gasification plants (NRC–15).

The commercialization of direct coal liquefaction is less advanced than coal gasification. However, large pilot plant programs are under way which, given sufficient market incentives, could lead to commercially viable processes toward the end of the decade. Production of usable fuels through coal liquefaction involves combining dissolved coal with hydrogen to yield a crude liquid, then refining the crude liquid to remove unwanted compounds (such as those containing nitrogen and sulfur) and to produce usable fuels. These fuels can include methane, light hydrocarbons, gasoline, jet fuel, diesel fuel, and fuel oils. Commercial feasibility depends in large measure on producing a crude liquid with a high concentration of usable components. In several processes this depends in turn on using catalysts to induce a high rate of selectivity among the chemical reaction processes (NRC–15; ENERGY).

A good deal of scientific research will be needed to improve the efficiency and reliability of future commercial synthetic fuel production and to minimize associated environmental problems. Priority research areas include those focused on mechanical and elastic properties of various coals, and on their chemical structures and compositions; on the ways in which noncarbon components of coal affect catalytic conversion processes; and on catalysis itself (NRC–14; ENERGY). First-generation commercial synthetic fuel products will probably mirror closely the natural gas and petroleum-derivative products that they will replace. However, particularly in the case of liquids, these products are not the most efficient ones to produce from coal. Methanol produced from synthesis gas (a mixture of carbon monoxide and hydrogen) is, for example, potentially a very good fuel. Likewise, hydrocarbon fuels with lower hydrogen-to-carbon ratios could be less expensive than presently used liquid fuels. In the future, as synthetic fuels from coal become more important, there will be increasing incentives to adapt engines and other combustion equipment to burn these alternative fuels (NRC–15).

LIMITATIONS ON THE USE OF COAL

Available domestic coal reserves could satisfy all U.S. energy needs and the needs of much of the industrial world for several decades into the next century. But there are limitations on its use. Water is needed in all coal mining processes both to repair environmental damage in strip mining and for producing synthetic fuels from coal. A good deal of the U.S. coal reserves are located in the semiarid West, where water-intensive agriculture is already limited by available water supplies. Mining and production processes that reduce water consumption, make use of available brackish water, and keep the discharge of pollutants into surface streams and rivers below acceptable limits will clearly be needed if the Nation is to substantially increase its use of coal (NRC–15). More efficient use of water for agriculture could also be an alternative, cost-effective option.

The production of carbon dioxide will very likely set the ultimate limit on burning all fossil fuels. Coal is, however, of special concern, since its low hydrogen-to-carbon ratio leads to the release of larger amounts of carbon dioxide for given amount of heat than most other hydrocarbon fuels. By the same token, the higher the ratio of carbon to hydrogen in a given fuel, the greater the amount of carbon dioxide that will be produced for a given amount of energy output. This circumstance argues in favor of using synthetic fuels with low carbon-to-hydrogen ratios. There is a great deal of uncertainty about how rates of increase in the atmospheric concentrations of carbon dioxide are related to rates of fossil fuel combustion, and also about the rates at which carbon dioxide can be reabsorbed by vegetation and the oceans. However, climatic effects might be measurable as early as the first decade of the 21st century, and few analysts are prepared to dispute the argument that if fossil fuels—primarily coal—were to remain as the principal source of energy in the industrial countries, serious problems would ensue by the middle of the century (NRC–15; ENERGY; NR). Thus, while coal, and fuels made from coal and shale, will be an essential component of the energy source mix that this country will rely upon until well into the next century, and while synthetic fuels may well be used indefinitely for some limited purposes, coal cannot provide the sole basis for future U.S.—or world—energy needs.

NUCLEAR FISSION

Most analysts agree that nuclear power will have to provide some fraction of U.S. energy needs for the remainder of the century, though the pace and direction of the development of nuclear energy remains highly uncertain. At present, a total of 72 nuclear power plants, all of which are based on light water fission reactors, provide about 13 percent of the Nation's electricity. By 1995 there could be as many as 190 light water reactor plants in operation supplying approximately 30 percent of the electricity used in the country. However, since forecasts of electricity demand growth during the next 10 years have recently been revised downward, this projection is subject to considerable uncertainty. Decreasing growth rates and future uncertainties have created serious problems for electric utilities which must design, capitalize, and begin constructing new plants years in advance of their anticipated use. Additionally, a burdensome regulatory climate derived in part from a lack of public confidence about the safety of nuclear power has led several utilities to cancel orders for nuclear power reactors. Indeed, no new reactors have been ordered by the utilities industry since 1978 (ENERGY). This slowdown in the development of nuclear power for generating electricity has been taken as evidence by some critics that *no* additional nuclear fission plants will be needed in the future.

The future of nuclear power in the United States will depend on changing economic and political factors, and these factors will be strongly influenced by emerging scientific and technological capabilities. Priority programs during the next 5 years will continue (1) to improve the safety and operating efficiency of the present generation of light water reactors, (2) to develop provisions for the permanent, safe disposal of high-level radioactive reactor wastes; and (3) to pursue exploratory research and development that will be required to commercialize advanced fission reactor systems.

Additionally, the feasibility of designing nuclear reactors for uses other than electricity generation could attract attention. These possible uses include supplying process heat for manufacturing and, significantly, for a synthetic fuel industry.

IMPROVING THE SAFETY AND EFFICIENCY OF LIGHT WATER REACTORS

Until the mid-1970s, the design of and the economics associated with presently operating light water reactors assumed that the spent fuel elements removed from the reactors would be reprocessed to separate the remaining uranium from the waste material, and that uranium would thereby become available for new fuel elements. Presently available reprocessing and recycling processes also separate out plutonium, which can be used for nuclear weapons (*Outlook I,* v. II, pp. 153–54, 160–61). This circumstance raised concerns about nuclear weapons proliferation and led, in 1977, to a moratorium on reprocessing plants construction in the United States. Although the President lifted this moratorium in October 1981, most light water reactors will almost certainly continue to operate in a once-through mode for several years. For that reason, there is considerable interest in improving the efficiency of power plants, since even small incremental gains can result in large economic benefits. Two approaches are being pursued: first, increasing the fraction of usable fuel that actually undergoes fission by using different fuel materials and core designs; second, using higher temperature coolants and more efficient turbines that can use a greater fraction of the heat produced in the reactor core to generate electricity (ENERGY).

Topics involving light water reactor safety that are being explored by Federally supported research include the man-machine interface in plant systems, improvements in reactor containment and improved means to minimize the release of radioactive gases into the biosphere, in response to public concerns about this topic. Studies aimed at an improved understanding of core melt accident phenomenology and at better methodologies for risk assessment are also being pursued. This refocused attention on reactor safety derives in part from the wide ranging public debate about nuclear safety that followed in the wake of the Three Mile Island accident in March 1979. It is worth noting the consensus of the Kemeny Commission that the failure at Three Mile Island was not with the nuclear reactor itself but, rather, with the coupling between the reactor and the more conventional parts of the plant where the steam produced by the heat in the reactor core generates electricity. Moreover, as the Commission pointed out, the control panels at Three Mile Island were badly designed so that it was difficult for operators to assess the problem that was developing in the system and take the proper corrective action. Indeed, a good deal of the control system could have been more automated. Finally, the operators themselves were inadequately trained to deal with emergency situations.[6] In short, the conclusions of the Kemeny Commission reaffirmed the inherent safety of light water nuclear reactors (ENERGY).

DISPOSAL OF HIGH-LEVEL WASTES

Adequate, permanent disposal of high-level nuclear wastes will continue to be both a policy and a technological issue during the next 5 years. At present, spent fuel elements removed from light water reactors are temporarily stored at various aboveground locations, and could remain in such locations indefinitely without constituting a public risk. Since the 1977 moratorium on reprocessing and recycling has been lifted, these elements could ultimately be reprocessed to recover reusable, fissionable materials. If such a procedure comes to be employed, the residual liquid, high-level, long-lived radioactive wastes could then be dried and encapsulated in an inert material such as glass, ceramic, or concrete prior to being sealed into canisters for ultimate underground disposal. Technologies for encapsulation in glass are well understood. A 2-year pilot test has been completed in France, though there are indications that certain ceramics are superior to glass from the perspectives of cost and process efficiency (NRC–8). The problem of isolating bulkier solid, intact, unreprocessed fuel rods from the environment prior to burial is somewhat different, and research aimed at resolving this problem will be pursued during the next 5 years (ENERGY).

There are a number of candidates available for deep, geological isolation of canistered wastes of either the liquid or solid type. These include cavities constructed in deep salt, basalt, or shale beds, volcanic tuff and granite, or related crystalline rock formations. National policy will focus on assessing the relative merits of these different geological options during the next 5 years, with disposal in the deep ocean floors a more distant possibility (NRC–8). Federal criteria for site selection and approval for the disposal of different waste forms based on these assessments will be refined during the next 5 years (ENERGY).

ADVANCED FISSION REACTOR SYSTEMS

At some future date, light water reactors may come to be regarded as sufficiently less efficient than other alternatives to justify shifts toward those advanced modes. Several such alternatives are being studied intensively in order to ensure the existence of the science and technology base for such a change in policy. The High Temperature Gas Reactor, which uses helium rather than water as a core coolant, is particularly attractive in this regard, because it could be used to provide industrial process heat and could also be suited for use in a converter mode with a uranium and thorium mixture rather than pure uranium used as its fuel (ENERGY).

Although reactors such as the High Temperature Gas Reactor are expected to burn fuel more efficiently than light water reactors, they would still use only a small fraction of the potential energy content of the U.S. uranium and thorium supplies. Present estimates of world uranium reserves indicate that light water reactors in the United States would have to begin to be retired around the end of the century unless more advanced systems were near commercialization by then. Converter reactors could stretch out the useful lifetime of nuclear fission as a viable energy source to some degree. However, Fissile Fuel Breeder Reactors, which could convert uranium and thorium into fissionable fuel at the same time they produce energy, would increase the effective fissile fuel supply by a factor of 100. Breeder reactors could be used either by themselves or as a source of fuel for light water or high-temperature gas reactors, thus providing utilities with a predictable quantity of and price guarantee for fissile fuel. Uranium and thorium would thereby become sustainable energy resources usable for the indefinite future. The Administration has proposed to continue the work of the Clinch River Liquid Metal Fast Breeder Reactor Facility. Meanwhile, additional, broadly based research and development efforts aimed at critical technical areas and the development of technical and engineering data that will permit the selection of a breeder system for possible deployment around the turn of the century are proceeding (ENERGY).

It is almost certain that the advanced nuclear energy option will be actively pursued somewhere, if not in the United States, since few countries are so richly endowed with the fossil fuel reserves that this country enjoys. France plans to demonstrate a large-scale commercial breeder reactor by the end of 1983, and the Soviet Union is making good progress with breeder technology. If either country succeeds in commercializing breeder reactors, there is little doubt that they will move to market both the reactors and reprocessing facilities abroad. France already has a reprocessing and recycling facility, and reprocessing is being actively pursued in the United Kingdom and Japan (NRC–14).

THE RELATIVE RISKS OF NUCLEAR POWER

Most analysts agree that there are risks associated with all specific future energy options. They disagree, however, about the magnitude of those risks and about their relative acceptability. The nature of the risks to health and the environment from coal and nuclear fission has been well advertised, although there is considerable disagreement about the seriousness of those risks—particularly those associated with nuclear fission. Barring a catastrophic nuclear accident and taking into account probable environmental effects of atmospheric carbon dioxide, the health, safety, and environmental risks associated with coal are probably greater than those associated with nuclear fission.[7]

There are, in addition, serious risks of a different kind that could result from prematurely curtailing or eliminating either or both the coal or the nuclear option. These include the risk of economic dislocation (and even warfare) that could result from placing too much faith in a narrow range of options that proved not to be viable. The differing nature of these risks and the fact that neither their future magnitude nor their future acceptability can be assessed at present again recommends for pursuing energy-related research and development across a wide front.

RENEWABLE RESOURCES

Renewable energy sources, including direct solar, biomass, geothermal, ocean, and wind, presently provide about 6 percent of the U.S. energy supply. For the most promising of these sources, notably solar and biomass, there will be a continuing need to improve the underlying science and technology base before they can make more significant contributions to the total U.S. energy supply. As in the case of other energy sources, the marketplace will determine the pace and direction of their development. Federal support will focus on developing underlying scientific bases. The removal of subsidies for competing petroleum technologies and various tax incentives should create a more favorable climate for capital investments in renewable energy sources, particularly solar sources (ENERGY).

DIRECT SOLAR ENERGY

Almost all analysts agree about the ultimate promise of solar energy. Indeed, direct solar energy, along with breeder and possibly fusion reactors, is probably the only available energy option for the very distant future, with synthetic fuels from coal and shale (or biomass) and hydrogen extracted from water used when transportable fuels are needed. Differences of opinion regarding the viability of solar energy focus on when various solar sources are likely to make a significant penetration into the market. Solar energy systems are, however, uniquely adaptable to decentralized user requirements and could therefore be usable on smaller scales than other future options. For that reason, their role in any assessment of future energy sources should not rely solely on their contribution to aggregate demand.

A variety of technologies for directly harnessing solar energy are under development, and applications of direct solar energy technology ranging from individual solar water heaters to centralized electricity generation have been studied. Currently, direct solar water and limited space heating systems are finding expanded application, although broadly functional systems are not expected to evolve until late in the present decade. Such systems currently have the disadvantage of having higher initial costs than do competing systems, although they also have the advantage of not requiring conventional fuels for their operation. Additional development will be needed before these kinds of systems can be used widely in a cost-effective way (ENERGY).

Photovoltaic systems are presently under consideration both for large, centralized applications and more modest, decentralized needs. Photovoltaic cells, which convert light directly into electricity, have now reached a research stage where conversion efficiencies in excess of 11 percent have been achieved. Reduction in the costs of photovoltaic systems may well require a new type of device based on thin amorphous films rather than presently used crystalline materials. The Federal Government is supporting long-term R&D on advanced semiconductor materials for such applications. Cost reductions are also expected with the introduction of large automated production facilities (ENERGY).

Beyond what can be accomplished through improvement of the cells themselves, the potential of photovoltaic systems could be enhanced by locating them outside the filtering effects of the Earth's atmosphere. This observation provides the basis for the concept of the Solar Satellite Power Station, which would consist of a very large array of photovoltaic cells in geosynchronous orbit. Solar power from the array could be transmitted in the form of high-frequency microwaves to receiving antennas on Earth, where it would be reconverted into electricity.[8] Since the science and technology underlying such systems are not well understood and the required capital investments would be very large, they are unlikely to become viable options in the foreseeable future (*Outlook I*, v. II, p. 159).

BIOMASS

Renewable organic materials such as vegetation or animal, agricultural, and forest residues are all classified as biomass. This organic material can either be burned directly, or used to produce liquid or gaseous fuels, or to produce chemicals as substitutes for chemical industry feedstocks that are presently derived from petroleum or natural gas. Since living plants store energy from the sun, biomass is often classified as a form of solar energy.

Fermentation of grains to produce alcohol is, of course, an established commercial technology, and the results of research and development leading to systems for the economic production of methanol and methane gas through fermentation of other vegetable and animal residues are promising (ENERGY). Basic research in plant genetics that could underlie advances in the biological engineering of plants could greatly enhance the potential of biomass as a significant, long-term energy option.

Wood is potentially a good source of fuel and chemicals produced through fermentation, although it requires considerable pretreatment before the fermentation process can be effective. Alternatively, wood can be used to produce synthetic fuels by means of the same basic processes (involving gasification for example) that are used to make these fuels from peat or coal (NRC–15). Given the present availability of coal, however, and the ecological problems involved in extensive cultivation of forests for biomass, this latter option does not appear to be a significant one for the United States during the foreseeable future.

NUCLEAR FUSION

Nuclear fusion, the process through which the sun converts its mass into energy, has the potential to be an important option for the long-term future. Most designs now regarded as feasible would make use of tritium derived from lithium (which is relatively abundant) and deuterium extracted from the oceans, so that commercial fusion reactor fuel sources would qualify as renewable.

Fusion occurs when two light nuclei react to combine into a heavier nucleus and give up excess energy in the process. Usable fusion reactors would be designed to convert that energy into electricity. Since fusion reaction processes can only occur at exceedingly high temperatures, the basic scientific and technical problems are associated with raising the temperature of the fuel and sustaining it at that temperature for the fraction of a second required for fusion to occur, while preventing the fusion reaction from being quenched through contact of the hot fuel with the confining container. Two approaches are being pursued: In the magnetic confinement method, the fuel is kept away from the container walls by an intense magnetic field as its temperature is raised. In the inertial confinement method, pellets containing the fuel are dropped successively through the common focal point of several intense pulsed laser or charged particle beams where the fuel temperature is raised abruptly.

Research aimed at solving some of the formidable problems associated with the magnetic confinement method has been under way for 20 or more years in this country and abroad, and present enthusiasm among those involved in that research is high. In 1980 the Congress enacted the Fusion Research, Development, and Demonstration Act, which commits the Nation to an aggressive program for the advancement of knowledge about fusion technology. The scientific feasibility of fusion power is likely to be demonstrated during the next 5 years at facilities that are now nearing completion in Princeton (*ASTR–III*). A roughly similar test facility of the European Community is nearing completion in England, as are test facilities in Japan and the Soviet Union.[9] Formidable technical problems will still remain to be solved, however, if a commercial-sized fusion power system is to be demonstrated by the year 2000, as envisioned by the Fusion Act (ENERGY).

Development of the inertial fusion method is considered essential to address current and future nuclear weapon design problems. During the next 5 years it is expected that the necessary energy levels will be obtained for fuel ignition using both laser and charged particle beam sources. NOVA, the highest power driven laser system, is presently scheduled to demonstrate that fusion can be induced by this method in 1983. A full demonstration of the scientific feasibility of the inertial approach could be ready in about 10 years (ENERGY).

IMPROVING ENERGY END-USE EFFICIENCY

Increased energy-use efficiencies—that is, energy conservation—can strengthen national efforts to ameliorate the energy problem in the near-term future, whereas energy derived from advanced technologies may take many years to make a meaningful contribution. Energy conservation will also remain an imperative for the long-range future regardless of what mix of sources is used. The decontrol of oil prices is expected to have a major impact on increasing energy-use efficiency (ENERGY).

Two types of measures are available for increasing end-use efficiency: those that permit substitution of scarce fuels with more abundant fuels; and those that permit *all* available energy to be used more efficiently. The first set of measures includes, most notably, using liquid fuels only where necessary. A number of utilities and a few large industries are converting from oil to coal, and power stations now under construction are designed to use coal, natural gas, and, in some instances, nuclear fuels. A good deal of attention is also being paid to developing systems that will allow small industries to use coal efficiently to generate process heat. All such efforts constitute the first type of energy-efficient measure (ENERGY).

Considerable progress toward implementing the second type of measure has also been made through car pooling, increased use of mass transit and smaller cars, and improved building insulation, for examples. Prospects for further improvements in the transportation sector are discussed in Section II–H.

Additional energy savings are anticipated in the next few years as manufacturing industries replace existing capital equipment with more energy-efficient stock, introduce energy-efficient processes, and make better use of industrial wastes (NRC–14). Many such measures can be taken by using or adapting existing technologies and are limited primarily by capitalization costs. Cogeneration is a particularly appealing possibility. It involves using industrial waste process heat rejected by a utility or large industry for other purposes, usually for heating (ENERGY). Ultimately, the use of stronger, lighter, more heat resistant materials should allow additional energy savings in all sectors, but primarily in transportation and manufacturing. The availability of such materials will, however, depend in part on research that is now in progress (NS; ENERGY; *Outlook I,* v. I, pp. 16–17, 20–21).

In general, the introduction of these and other energy-efficient measures in the industrial sector should permit a substantial increase in economic activity by the end of the decade (ENERGY). Considerable near-term energy savings are also anticipated in agriculture, as discussed in Section II–I.

INTERNATIONAL PERSPECTIVES

While the focus of this discussion is on the United States, it is clear that since problems associated with energy are worldwide, likely effects on other countries will of necessity condition planning in this country. In particular, the security of the United States gives this country a vital stake in the economics and, thus, the energy supplies available to its allies. Since the more important effects that the energy problem is likely to have abroad are discussed in detail in Section I–D, they will only be summarized here.

First, despite the current leveling of international prices for petroleum, these prices are almost certain to increase in the future as world demand increases and the supplies themselves level off. Part of the increased world demand will result from growth in the world's population. Additionally, middle-tier countries of the third world, including several OPEC countries, are expected to increase their demands significantly during the next 10 or 20 years, and the U.S.S.R. may also have to begin importing oil by the early 1990s.[10] This increasing international competition for petroleum may well result in increased occasions for international irritation and tension. The United States can mitigate these effects on itself by reducing its own dependence on oil imports as much as practicable, thus, in effect, backing off as far as possible from the competition.

Second, it is worth noting that the world energy problem need not be entirely disadvantageous to the United States. This country can continue to gain trade advantages as an exporter of energy technology, as with other high technology. Moreover, since coal will almost certainly become a prime alternative to petroleum for industrial and utility boilers within a very few years, and since 30 percent of the world's coal supplies are in the United States, we could become a principal exporter both of coal and of fuels made from coal. The availability of synthetic fuels from the United States would also permit the industrialized democracies to reduce their dependence on Middle Eastern petroleum as a source of liquid fuels.[11] These circumstances suggest that there can be other incentives, in addition to expected escalating petroleum prices, for developing a synthetic fuels industry.

Finally, there are and will continue to be numerous opportunities for international cooperation in energy research and development that can benefit the United States. Several U.S. synthetic fuel demonstration programs have German and Japanese participants, for example. A central problem in all cooperative research and development programs is how to distinguish between cooperative projects that will yield long-term net benefits to the United States and those that may give other countries an unwarranted competitive edge. A useful rule of thumb has been to cooperate in projects that are very expensive (so that substantial short-term savings are possible) and that focus on research that is unlikely to be applied to our disadvantage in the short term. Fusion research qualifies as an appropriate area for cooperation according to this criterion. However, it may also be desirable to cooperate in fields with more immediate payoffs. For example, multinational consortia or new multinational companies may well be needed to develop a viable world nuclear reactor construction industry (NRC–14).

With regard to international cooperation, it is worth noting that no other country has the resources to maintain as widespread an energy research and development program as the United States, and few are so richly endowed with fossil fuel reserves. As a result, there has been more specialization overseas on technological options considered appropriate to specific national situations, such as the breeder reactors in France, the United Kingdom, the Soviet Union, and Japan; solar and geothermal energy in Japan; ethanol from biomass in Brazil; and production of synthetic fuels from coal in West Germany and South Africa (NRC–14). As world petroleum prices continue to rise, the incentives for the United States to engage in more cooperative research and development projects and thus to exploit some of the advances being made abroad is likely to increase.

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F. Natural Resources

One of the major elements in the progress of our civilization has been the availability of a rich and varied supply of natural resources, and at one time it seemed that the stocks of naturally occurring resources that yielded food, shelter, fuels, and other necessities of life were inexhaustible. However, an ever-increasing world population, coupled with continued rapid industrial growth, is placing such demands on those resources that there is increased concern that Earth's resources may not keep pace with the demands of future generations. The world's population increased by 1.9 billion, or over 75 percent, between 1950 and 1980 to the currently estimated level of 4.4 billion, and current projections are that world population will reach about 6 billion people by the end of the century (AAAS–9). On the basis of those projections about population growth and world development, there have been warnings, for example, that the availability of fuelwood and wood products could continue to decline as forested areas are used for other purposes; that shortages in, and the quality of, water in many parts of the world may worsen; that increased desertification of lands may occur, with a resultant loss of range and cropland; and that further population growth in some geographical areas could be severely limited by Earth's capacity to support life.[1]

It is important to recognize that those dismal projections are extrapolations and not predictions. They depict conditions that are likely to occur if there are no changes in public policies, institutions, or rates of technological development, and if there is no war or other major disruption (NRC–1). Therefore, they should be viewed as warning signals, pointing out areas that demand continued and serious attention in the coming years and emphasizing the urgency of emerging problems in natural resources and the environment.

Although there may ultimately be shortages in the global supply of resources, problems for the near future will lie more in the way those resources are distributed geographically, and in their political and economic availability, than with their potential physical exhaustion (NRC–1; AAAS–10). For example, a fresh-water shortage for the world at large is not likely for centuries, but severe shortages do exist today in some parts of the United States and in some Middle Eastern and African countries. A similar situation exists for other resources that are distributed unequally among countries and that may be unavailable to the countries in short supply because of trade restrictions or economic costs (NRC–Obs.; AAAS–10).

Science and technology can mitigate many potential natural resources problems. For example, if an inexpensive and renewable energy source were to be developed, saline water could be converted to fresh water for food production, clean-burning hydrogen fuels could be produced in quantity, and many scarce minerals that occur in low-grade deposits could be extracted and processed economically (NRC–1). But, it is not expected that such an energy source will be widely available for several decades. In the interim, other technological advances can lessen, although perhaps not immediately solve, many of the resource problems that have been projected, and the development and application of those technological advances are dependent on concerted policy actions in the next 5 years. Several current and emerging problems in natural resources are discussed below.

ENSURING AN ADEQUATE SUPPLY OF NONFUEL MINERALS

Current trends suggest that the worldwide consumption of major nonfuel mineral commodities will increase steadily for the rest of the century, slightly more than doubling current demand by the year 2000. While there is little concern that the sources of those minerals will become physically exhausted during that period, there are major concerns that supplies to industrialized countries might be disrupted either by price manipulations or for political reasons (AAAS–10; IA).

The major identified global reserves of several minerals important to the economies of the United States and other industrialized countries, such as cobalt, chromium, manganese, platinum, bauxite, and copper, are located in a few developing countries. In the past, those minerals usually were readily available and inexpensive in the world markets. However, many mineral-producing nations have begun to increase their export earnings through steady price increases. The high prices, coupled with the political instability that characterizes many of the countries with large mineral resources, pose the danger of those commodities eventually becoming too expensive for cost-effective American use, or of there eventually being major disruptions in the availability of critical nonfuel minerals for use in the United States and in other industrialized nations (AAAS–10; IA).

Providing for an adequate supply of nonfuel minerals has two time frames. In the short term (5–10 years), there is little that science and technology can contribute in preparation for dealing with potential supply interruptions—either those due to cost factors or those occurring for other reasons. Most science- and technology-based strategies for ensuring an adequate mineral supply take many years before they pay off. Therefore, our present strategy, for the near term, is based on establishing and maintaining a stockpile of critical materials.

On the other hand, many suggested courses of action for preparing the United States for potential supply interruptions in the longer term are heavily dependent on scientific and technological activities. Three interrelated approaches are discussed below. One is to expand the resource base available to the country through further mineral exploration. A second approach is to improve both mining and processing technologies so that new sites can be exploited and existing mining and processing activities can be carried out more efficiently. The third approach is to develop materials that can be substituted for those minerals whose supply is threatened.

ENHANCING THE AVAILABLE RESOURCE BASE

One way to counteract a potential interruption in the supply of minerals for use by the United States is to locate additional mineral resources in sites more accessible to the country. However, excluding the State of Alaska, the United States is one of the most thoroughly prospected nations of the world, and that raises two kinds of problems. First, so much of the country has already been prospected that heretofore protected national lands would have to be explored; consequently, problems connected with proprietorship and the need to protect land resources and the environment would be raised. Second, and with more relevance to a need for science and technology developments, the vast majority of large shallow deposits of high-grade ore has already been found and have been, or are being, mined. Therefore, to enhance the available resource base, attention would have to be focused on locating and then exploiting currently untapped reserves, such as deep and concealed deposits. The necessary technologies are in many cases not yet fully developed, and ores from those sources are frequently of low quality.

Adequate mineral exploration technologies will have to be developed that are capable of both detecting and assessing such things as deep or concealed ore deposits. That capability, in turn, will rest not only on the development of new instruments to detect anomalous concentrations of minerals, but on new knowledge of the ways in which mineral deposits are formed and concentrated in Earth's crust. Therefore, in addition to needing new technologies, more information will have to be acquired in such basic areas as geodynamics and metallogenesis (NRC–17; AAAS–10; NR).

Additionally, there is the possibility of increasing the mining of the ocean floor. Nonfuel minerals currently are taken from only a few, near-shore, shallow-water locations, but there is wide agreement that much more extensive deposits of such critical minerals as manganese oxides exist on or just below the surface of the deep ocean floor. Whether or not such potential deep-sea deposits will be located and then mined is as much a political as a technical question, since the interested countries have not yet agreed on who has the mining rights to those areas (NRC–17).

IMPROVING MINING AND PROCESSING TECHNOLOGIES

Once additional deposits have been found, they must be mined and their ores processed. However, the international competitive position of the domestic minerals producing sector is already declining, and conventional technologies for mining at large depths are becoming increasingly prohibitive for reasons of safety, energy costs, and large investment requirements. Those factors have led to a decline in the competitive position of the domestic minerals producing sector and have, thereby, inhibited production and deterred the search for new deposits.[2]

Science and technology developments could play an important role in reducing the costs of producing both primary minerals and the industrial products that are derived from them, thereby stimulating those industries and resulting in greater domestic supplies. For example, the handling and transport of mine materials, particularly in mines that lie 300 feet or more beneath the surface, incur enormous energy costs, and technological refinements could alleviate some of those costs. Work is needed, for instance, to further develop in-mine ore crushing and separation technologies that could minimize the amount of materials to be transported out of the mine (NR). Advances in solution mining promise improvements in miner safety, reduced disturbance of the surface environment, and a reduction in the amount of rock needed to be handled and disposed of in the mining process (NRC–17).

Approximately 10 percent of U.S. energy consumption is used and/or lost in the primary conversion of minerals into metals and other materials, and many research opportunities exist for increasing the efficiency of energy utilization in those processes. Additional opportunities for technological improvements can be found throughout the mining and utilization processes (NRC–17; AAAS–10). Thus, scientific and technological developments in mining and processing technologies could, by easing the financial burdens on American mining and minerals processing industries, lead to increases in domestic supplies of critical minerals.

DEVELOPING SUBSTITUTE MATERIALS

A third way that science and technology can help resolve long-term shortages in critical nonfuel minerals is through the development of alternative materials that could be substituted for those made with the potentially threatened commodities on which industrialized nations now highly depend. For example, recent achievements of the U.S. defense and space R&D programs have demonstrated some substitution opportunities for critical and scarce mineral commodities. Carbon fiber-reinforced carbon composite materials, for instance, could potentially be substituted for superalloys using nickel and cobalt in such applications as gas turbine engines. Additionally, new metal-matrix composites are potential substitutes for such critical materials as chromium, titanium, and beryllium. Furthermore, rapid solidification technology can provide very high quality starting materials for new families of aluminum and titanium alloys, as well as superalloys, while not using such scarce materials as chromium (NS). Thus, one approach, well into development stages, for dealing with potential shortages in critical nonfuel minerals is to reduce our dependence on them by developing viable substitutes.

PROVIDING FOR A SUFFICIENT SUPPLY OF WATER

Of our natural resources, water is one of the most important. In addition to personal use, water is critical for such enterprises as agriculture and energy production, and it is vital to virtually all industries. Two intimately related aspects of our water resources will demand attention in the next 5 years. The first is the supply of water, and the second is the quality of that supply. The interrelationship between the two is important, since the quality of the water supply is a critical factor in its functional utility and, therefore, overall availability. Since the topic of water quality is discussed in the next section, this discussion will focus only on the question of overall water supply.

There is no overall shortage of water in the United States. The total amount withdrawn from surface- and ground-water sources for public water supply systems in 1975 (the last year for which accurate figures are available) was about 27 billion gallons a day, or about 6 percent of the average annual flow of the Mississippi River at New Orleans. In addition, less than one fourth of the withdrawn water was consumed and unavailable for reuse after treatment (NRC–7). However, there are dramatic instances of regional and local scarcities from time to time, and the consequences of those shortages have made effective utilization, conservation, and distribution of water an important national priority and a factor in our international relations (NRC–7; *ASTR–III*). The U.S. Water Resources Council has reported that seasonal shortages are common in 20 percent of the 106 watershed regions of the country, and that number is projected to reach 40 percent by the year 2000.[3] In certain western regions of the United States, seasonal shortages are the rule rather than the exception, and those water shortages are exacerbated by current major population shifts, with consequent increases in water demand for personal use and, especially, for energy production (NRC–7). Moreover, the Western Research Committee recently reported to the Joint Council on Food and Agriculture a projected need for 20 percent more water over the next 20 years in the western region.[4]

Ensuring adequate water supplies is primarily a nonscientific or nontechnical issue. Problems associated with water availability generally are a result of competition within geographical areas between water needs for agricultural purposes and those for energy producton, or between those kinds of needs and those for other industrial purposes; the allocation and reallocation of water among the competing needs are primarily nontechnical policy decisions. But science and technology activities may be able to lessen the problems in the coming years by providing technological options for redistributing water, increasing the available supply, or increasing the efficiency of water use.

REDISTRIBUTION OF WATER

Of the options available for resolving water scarcity problems, redistributing water is clearly the most difficult politically. However, assuming that institutional or political barriers to interbasin transfers could be overcome, scientific and technological advances could be useful in providing more effective mechanisms for redistributing water from areas of high supply to those of low supply. Many attempts have already been made at finding the best means for redistributing water, including piping and redirecting streams and river flow patterns. But, again, those solutions have major political, ecological, and environmental ramifications. Redistributing water can reduce both the quality and the quantity of water resources elsewhere. Therefore, until new and more acceptable techniques are developed or the tried techniques are substantially improved, and until policy decisions are made that remove the institutional barriers to redistribution, water redistribution will prove almost certainly to be an ineffective mechanism for ensuring adequate supplies of water in all regions.

INCREASING THE AVAILABLE SUPPLY

There is some potential for increasing the available supply of usable water through scientific and technological development. For example, there always is the possibility of identifying and exploiting additional ground-water supplies, and the U.S. Geological Survey has initiated a major program directed to that goal. Another approach would be to increase efforts at converting seawater or brackish water to useful quality (NR; ENVIRON; *ASTR–III*).

It also is possible to increase the amount of water available in water-scarce regions by artificial means. Cloud seeding and other forms of climate change may be able to increase regional water supplies by as much as 10 percent (*ASTR-III*). However, any attempts at altering climatic conditions would have to be undertaken with full consideration of the complex ecological, social, and political ramifications.

INCREASING THE EFFICIENCY OF WATER USE

The problems of regional water shortages in the coming years can be lessened by technologies for increasing the efficiency of water use, for aiding conservation, and for increasing the potential for water reuse. Technological advances that increase both industrial and domestic water-use efficiency already have aided conservation efforts. Some progress has also been made in controlling water loss from agriculture and from urban runoff. In addition, some water recycling and desalination programs have been initiated and, although currently expensive, show some promise for functionally increasing the amount of water available for a variety of uses. At the forefront of the research effort, the Department of Agriculture is sponsoring research directed at developing less water intensive crops, and the National Science Foundation supports investigations into crops that can grow in water of high salinity (AGR; *Outlook I; ASTR-III*). However, to exploit fully the potential for water conservation and reuse, additional efforts of those kinds, coupled with policy decisions fostering the efforts, will be needed during the next 5 years.

PRESERVING THE WORLD'S TROPICAL FORESTS

Depletion of a nation's natural resources to provide the basic necessities of life or to improve living standards can pose major conflicts between short-term and long-term interests. That kind of problem is exemplified by the world's forest resources, which currently are seriously threatened. The spread of agriculture, the harvesting of timber, and the clearing of forest land for grazing have contributed greatly to serious deforestation in many parts of the world, presenting many potential problems for the future.

Over the past 20 years, forest coverage of the world's land surface has been reduced from over 25 percent to 20 percent. At current loss rates, coverage is projected to drop to 17 percent during the next 22 years and to stabilize around the year 2020, when only about 14 percent of Earth's land surface will be forested. Much of the forest loss will occur in tropical forests in developing countries, where it is estimated that all physically accessible forests will have been cut down by the year 2020. The loss of that resource to the people of the developing countries, who use 90 percent of the cut wood for cooking and heating, could be catastrophic.[5]

Such large losses will also have far-reaching effects that go beyond the areas where deforestation will occur. Rapid and widespread loss of the world's tropical forests will adversely affect absorption and retention of rainfall, causing widespread runoff and soil erosion. Regional temperature and rainfall patterns could be altered, affecting agricultural production and water supply in areas far removed from the deforested lands, and some plant and animal species would be lost and the total diversity of species greatly reduced. Additionally, large-scale reductions in vegetation could seriously affect Earth's capacity to reabsorb carbon dioxide from the atmosphere (NR).

Although the United States contains only about 1 percent of the world's tropical forests, their preservation throughout the world is of direct interest to this country. Tropical forests are a major source of specialty woods and pharmaceuticals exported to the United States and other nations. In addition, the flooding, loss of land for agricultural purposes, and growing scarcity of fuelwood due to forest loss combine to deepen social and economic problems in the deforested countries, adding pressures for massive migration of people and increasing the potential for political instability.[6]

As in the case of water resources, world deforestation is primarily a social/political/managerial problem involving balances among competing needs and sectors of society. Science and technology can therefore affect it only marginally. In its December 1980 report, the U.S. Interagency Task Force on Tropical Forests recommended a variety of policy actions. Included were two directly related to science and technology activities: first, the Task Force recommended initiation of an internationally coordinated action program on tropical forest research; second, it recommended doubling of the worldwide rate of reforestation and afforestation, activities that are heavily science and technology based (NR). In addition, better analysis of the potential political, economic, and social consequences of severe deforestation is warranted so that effective counteractive measures can be developed (SSRC–1).

COMBATING THE DESERTIFICATION OF LANDS

Agriculture, wood cutting, and overgrazing of rangeland are increasing the spread of desertlike conditions in the world's land areas, especially in less developed countries. The process has been termed "desertification" and involves the sustained decline and/or destruction of the productivity of arid and semiarid lands. Where the process is unchecked, land becomes unfit for range or crops (NR).

About one third of the total world land is arid, and it supports about one seventh of the global population. That arid land is widely threatened. Present global losses to desertification are estimated to be about 6 million hectares annually (an area approximating the size of Maine), and the world's desert areas are projected to increase from their current 800 million hectares by another 20 percent by the year 2000.[7]

While the problem is most serious in less developed countries, agricultural productivity is being affected by desertification in many industrialized countries, including the United States. The increased use of chemical fertilizers, water, and herbicides and pesticides has compensated somewhat for declines in soil conditions in the industrialized regions. But these products are expensive, and chemical fertilizers and pesticides can also damage the soil and cause other environmental problems.[8]

Although much of the problem is political and managerial in nature, there are some opportunities for science and technology to contribute to the alleviation of desertification and its impacts. Opportunities include design of research and development programs on salt-tolerant crops and vegetative covering, increased attention to the possibility of developing economic uses for naturally occurring arid plants, rehabilitation of degraded lands, introduction of operational desertification monitoring techniques, and improvement in techniques for managing surface-water and ground-water reservoirs. Those kinds of scientific and technological efforts provide an opportunity to lessen the impacts of or partially reverse the trends toward desertification in our arid and semiarid lands in the coming years (NR).

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G. Environment

The decade of the 1970s was filled with a great amount of activity directed at protecting the natural environment. Throughout those years, scientific and technological activities were coupled with both private and governmental efforts to overcome the progressive degradation of the air, water, and soil on which our productivity, health, and safety depend. By the end of the decade, the national effort to control pollution and upgrade the quality of our environment had made some impressive gains. Substantial improvements were made in urban concentrations of carbon monoxide, sulfur dioxide, and total suspended particulates; the steady deterioration in the quality of the Nation's surface waters was slowed; several substances known or suspected to be carcinogenic were withdrawn from permissible use; and substantial progress was made in identifying endangered or threatened species and in taking measures to protect them.

However, in spite of some reversals of long-term negative trends in the natural environment, we still have very limited knowledge about our environment, and in many respects that lack of knowledge has limited our ability to manage and protect our resources. Moreover, many environmental problems cross national boundaries (IA), and the mechanisms for adjusting conflicting environmental interests are poorly developed (Section I-D). Even within our own borders, many environmental problems are showing strong resistance to scientific or technological control. As a result, many Federal regulations that were framed with reference to maximum permissible pollution standards without regard to available control technologies have proven to be far more costly than anticipated and, in many cases, not as effective as had been hoped (NRC–14). Moreover, there is a growing consensus that, on balance, many Federal environmental regulations have constrained industrial innovation and economic growth (Sections I-C, I-E). For that reason, the President issued, on February 17, 1981, an Executive Order calling for greater precision in assessing both the need for and the potential costs of a broad class of Federal regulations, including those designed to protect the environment from technological hazards.[1]

With an increased emphasis on national economic recovery and enhanced industrial innovation, the 1980s likely will witness a more precise focus on trying to understand the nature of the risks due to several classes of widely acknowledged potential environmental hazards. At the same time, means will be sought to ameliorate the effects of those hazards in ways that are consistent with a broad range of national goals in addition to environmental protection. The goals include, for example, sustained economic growth and energy security. Finally, long-range efforts to deepen our understanding of the nature of the total biosphere will have to be pursued.

High-priority problems associated with science and technology that could be profitably pursued during the next 5 years include managing atmospheric effects of fossil fuels, controlling hazardous and toxic substances, protecting water quality, and minimizing air pollution.

ATMOSPHERIC EFFECTS OF FOSSIL FUELS

The use of fossil fuels and, especially, coal as sources of energy has important implications for the environment, and those environmental problems may have to be part of the complex of factors used in framing specific energy-related policy decisions (Section II-E). Atmospheric effects could be particularly serious.

THE CARBON DIOXIDE PROBLEM

The burning of fossil fuels releases carbon dioxide (CO_2) into the atmosphere and exacerbates already existing trends toward increased atmospheric concentrations of that substance. Coal use is especially problematic, because coal's low hydrogen-to-carbon ratio leads to the release of larger amounts of CO_2 for a given amount of heat than other fossil fuels (NRC–15).

The precise relationship between fossil fuel use and atmospheric CO_2 levels is not yet fully understood, nor is the range of potential effects that increased CO_2 levels might have. However, significantly increased atmospheric concentrations of CO_2 could have far-ranging consequences. For example, a doubling of current atmospheric CO_2 levels could result in marked changes in Earth's climate, by as much as several degrees in some regions (NRC–15). Those climatic changes, in turn, could have very broad effects, including adverse effects on the productivity of prime agricultural land and flooding of coastal areas due to partial melting of polar ice. Thus, although there remains considerable uncertainty about the precise relationships among fossil fuel use, CO_2 release into the atmosphere, and consequent effects on world conditions, there is general agreement that excessive burning of fossil fuels could be accompanied by the serious danger of upsetting world climatic and ecological conditions. There is still considerable uncertainty about how rates of increase in the atmospheric concentration of CO_2 are related to rates of fossil fuel combustion, about global atmospheric circulation patterns, and about the rate at which CO_2 can be reabsorbed by vegetation and the oceans (ENERGY). A high priority during the next 5 years will be to learn more about the details of the CO_2 problem so that information can be factored into long-range global energy and environmental planning (NRC–15; ENERGY).

ACID PRECIPITATION

A second, more immediate problem associated with, and exacerbated by, fossil fuel combustion is acid precipitation, most frequently identified as "acid rain." Rainfall is generally slightly acidic, with a normal pH of 5.6. However, reports place current rainfall pH levels in certain parts of the eastern half of the United States at 4.0 to 4.5, with some recorded levels as low as 3.0—in other words, at the acidity level of lemon juice.[2]

The two principal artificial sources of precursors to acid rain are oxides of sulfur and oxides of nitrogen, both of which are products of the combustion of contaminants in coal and oil (ENERGY). Emissions of sulfur and nitrogen oxides can react in the atmosphere to form sulfuric and nitric acid, which precipitate out with rain or snow, sometimes hundreds or thousands of miles from the emission source. The acid precipitation can have effects on fish survival, forest growth, communities of aquatic organisms, biomass production, survival of amphibian species, and agricultural yields. Such effects are widespread in eastern North America and the Western United States and are now recognized as major problems in Japan and northern Europe.

The control of acid rain through point source regulation of stack emissions is difficult because sulfur and nitrogen oxides do not show up on monitors of ambient concentrations of those substances, because of long-range transport problems, and because of the increasing practice of emitting gases through extremely tall stacks. The latter practice avoids ground-level concentrations but can lead to high-altitude mixing and chemical transformation, which complicate accurate source tracing.[3] Some progress is being made through industrial emission control efforts, but continued national and international cooperative research will be needed on the identification, control, and monitoring of the sources; transport media; chemical transformations; and environmental and health effects of the oxides of sulfur and nitrogen.

MANAGING HAZARDOUS AND TOXIC SUBSTANCES

The products of the U.S. chemical industry have yielded enormous benefits to society in the form of fertilizers, pesticides, pharmaceuticals, synthetic fibers, disinfectants, and a host of other products now routinely used in agriculture, industry, commerce, and medicine. Along with those benefits, however, are a number of associated known or suspected dangers to human health and to the environment. Many chemicals are vital to human survival in low concentrations, but highly toxic in higher concentrations; others are highly toxic at all concentrations. Some are highly persistent and do not break down physiochemically or degrade biologically; certain otherwise harmless chemicals can interact to form highly toxic agents, pollute the atmosphere, and contaminate groundwater supplies (*Outlook I*).

Recognition of the dangers to human health and the environment has spawned a substantial body of legislation to control hazardous and toxic substances, including the Toxic Substance Control Act and culminating in the passage in December 1980 of the Comprehensive Environmental Response, Compensation, and Liability Act (the so-called "Superfund" bill). The latter provides for a cleanup fund for hazardous substance spills and for neutralizing inactive hazardous waste disposal sites.[4] Over the next 5 years, additional scientific and technological activity will be important for learning more about containing emergency spills and treating and disposing of hazardous wastes.

EMERGENCY SPILLS

Hazardous wastes are typically thought of as those that are ignitable, corrosive, reactive, or toxic. About 15,000 accidental spills of oil and hazardous substances are reported annually in the United States (ENVIRON). While most of these are relatively small, the oil spill in the Santa Barbara Channel in 1969, the 216,000 tons of crude oil spilled in the English Channel by the Amoco Cadiz in 1978, and the June 3, 1979, blowout in Campeche Bay, Mexico have focused public and governmental attention on the environmental hazards of oil spills. Those kinds of spills are a particularly complex problem: they generally affect all aspects of our environment, including air, land, and water, although not all equally and for varying periods of time. As a consequence, the problems that spills present are extremely diverse, involving a multidimensional matrix of spilled substances, volume spilled, location and condition of the spill site, and weather (ENVIRON). Various techniques are emerging as likely candidates for handling spill problems, including dispersant agents for offshore spills and new bacterial technologies to provide cleanup agents. However, additional technologies are needed over the next 5 years to detect, contain, clean up, and mitigate the effects of spills of oil and hazardous substances in more cost-effective ways (ENVIRON).

MANAGING WASTES

It is estimated that 45 million metric tons of hazardous wastes are currently generated in the United States in a year, and those must eventually find their way to disposal sites, about 2,000 of which currently might be considered "problem sites" (ENVIRON). The Resource Conservation and Recovery Act of 1976 (P.L. 94–580) recognized the problems posed by hazardous wastes and recommended initial remedial approaches. Recently, public attention has focused heavily on the efficacy of waste disposal sites as a result of widely publicized incidents at Love Canal, New York; Legler, New Jersey; and Gassville, Arkansas. Those incidents, in combination with the need to dispose of wastes in a safe manner, present a growing challenge in the coming years both for science and technology and for policymakers responsible for managing waste handling.

A variety of technical approaches can be taken in dealing with waste problems. One approach is to reduce the quantity of certain hazardous wastes produced or released at their point of origin. A second approach is to find better means for transporting, storing, treating, and disposing of those industrial wastes for which no acceptable means of elimination or reuse has been developed. A third approach is to develop methods to remove and/or recover hazardous materials from waste streams during waste disposal operations (ENVIRON). Although the choice of strategies is not solely a matter of science or technology—it also involves economic and political factors—science and technology are intricate parts of all of those strategies and, therefore, are presented with a major opportunity to help solve waste disposal problems over the next 5 years and beyond.

IMPROVING WATER QUALITY

Maintaining a high level of water quality in the face of increased water demands is a critical national problem; high-quality water is needed for personal consumption, and for industrial, agricultural, and recreational purposes. Many of our water sources are of less than adequate quality, and although it has been reported that the Nation's surface-water supplies are not diminishing in quality, they also are not getting any better, and there is increasing concern about the quality of our ground-water supplies (NRC–7). Nonetheless, the lack of further deterioration in the quality of at least the Nation's surface waters, in the face of a growing population and expanded economic activity, is a major accomplishment in water pollution control.

The Nation's efforts to cleanse its waters were facilitated by passage of the Federal Water Pollution Act Amendments of 1972, which, following enactment of additional amendments in 1977, became known as the Clean Water Act. That Act called for a general strategy of controlling water pollution at its source, rather than relying simply on cleaning up receiving waters. The technology-based uniform national standards approach to controlling municipal and industrial point source pollution is now generally expected to achieve marked improvements in point source control.[5] However, experience with that approach has revealed some previously unanticipated problems toward which science and technology efforts might be directed. Some of those problems are discussed briefly below.

PROTECTING GROUND-WATER QUALITY

The program implemented by the Clean Water Act concentrated on cleanup of surface waters, there being an implicit assumption that the Nation's ground water was relatively clean. Recent evidence suggests , however, that renewable ground water, which is approximately 50 times more plentiful than the annual flow of surface water, is itself vulnerable to contamination, primarily from human activities. The sources of pollution include sewage treatment plants, landfills, and industrial waste disposal. Additional scientific and technological information will be needed to develop and validate equipment and technologies for sampling and monitoring ground-water quality; for developing and standardizing soil permeability tests for industrial wastes containing organic solvents; and for the determination of the toxicity of chemicals that are likely to contaminate ground-water supplies, particularly synthetic organic chemicals (NRC–7; ENVIRON).

CONTROLLING NONPOINT SOURCES OF POLLUTION

Nonpoint source pollution, which is the origin of more than half of the pollutants that enter the Nation's waters, is a result of a variety of factors, including localized agricultural activities, urban storm water runoff, individual wastewater disposal systems, and airborne contaminants (NRC–7). A more detailed discussion of the problem appears in the *Source Volumes* (NRC–7). Controlling nonpoint sources of water pollution is, however, a far more complex problem than controlling point sources.

CONTROLLING TOXIC POLLUTANTS

The 1977 Clean Water Act amendments marked a milestone in the regulation of the industrial water pollution control program, as emphasis was shifted away from control of such conventional pollutants as total suspended solids, fecal coliform bacteria, oil and grease, and phosphorus toward such toxic pollutants as chlorinated hydrocarbons, solvents, and heavy metals.[6] Regulations were issued for the control of 65 classes of priority toxic pollutants, established in the amendments as a result of a consent decree, and the Environmental Protection Agency (EPA) has proposed effluent limitations for nine primary industries (ENVIRON). In proposing best available technology effluent limitations, EPA incorporated an "indicator strategy," by which limitations were placed, in some cases, not on the priority pollutants, for which data were difficult or costly to obtain, but on "indicator" pollutants, which have similar physical and chemical properties and are responsive to similar treatment mechanisms. Additional research efforts will be needed over the next 5 years to fill gaps in existing health and ecological data to support proposed water quality criteria for priority toxic pollutants (ENVIRON).

TREATING POLLUTED WATER

An additional approach to the water pollution problem is to treat water once it has been polluted. Technologies are being developed that might aid in the recovery of polluted water, thus potentially alleviating some of the strains placed on local water supplies (discussed in the natural resources section of this chapter) and providing for a healthier environment. Some progress has already been made, for example, in desalinating water in areas of ground-water overdraft (*ASTR–III*). However, many conventional and new technologies for treating polluted water are highly expensive and energy inefficient. Additional concerted multidisciplinary efforts aimed at developing better techniques both for monitoring the level of contaminants in the water supply and for treating polluted water will be needed in the next 5 years (NRC–7; ENVIRON).

COMBATING AIR POLLUTION

One aspect of air pollution—the atmospheric effects resulting from the continued use of fossil fuels as an energy source—has already been discussed in this section. However, there are many other sources of air pollution that will require attention during the coming years. The substantial effort to clean up the Nation's air, starting in the 1960s and stimulated by the Clean Air Act amendments of 1970 and subsequent amendments, has made impressive gains. Of the five "criteria air pollutants" now routinely monitored—sulfur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO), ozone, and total suspended particulates (TSP)—three (CO, SO_2, and TSP) have been lowered nationally, while ozone concentrations have remained stable. Oxides of nitrogen, on the other hand, remain at high levels.[7]

According to a variety of experts, attention during the coming years will need to be increasingly focused on health-related aspects of airborne pollutants, particularly on airborne carcinogens (ENVIRON). Continuing research will be needed on the health and environmental effects of oxidants, gases, and particles, as well as on the above-mentioned effects of fossil fuels combustion. Over the next 5 years, additional efforts will be needed to characterize toxic organic chemicals and their atmospheric fates, to determine the extent of human exposure to those chemicals, and to quantify the relationships of those chemicals to respiratory infections, asthma, emphysema, neurological disorders, and other diseases.

During the past years, increased attention has also focused on indoor air quality, a matter of increasing public concern as energy conservation measures improve household insulation and reduce ventilation. Continuing studies will be needed of the health effects of increased indoor concentrations of carbon monoxide and nitrogen dioxide, as well as the health effects of greater exposure to the formaldehyde common in foam insulation, resins, furniture, carpets, and drapes. Scientific advances will be needed to form a base from which adequate and appropriate strategies, both technological and nontechnological, for combating air pollution and minimizing its effects might be developed.

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H. Transportation

Mobility is a trait deeply imbedded in the national character of the United States. It has been a major feature of American social and economic culture since the founding of the Nation. As the United States grew and developed, mobility became institutionalized into our way of life by the interplay of social, political, economic, and technological forces. Two centuries of development resulted in a national transportation system that is accessible, flexible, and sufficiently efficient to come within the reach of and be used by virtually every citizen.

Improving the mobility of people and products was the overriding goal for transportation through the first half of the century, and, until the 1970s, the major issues in transportation were dominated solely by that goal. During the 1970s, however, the primary issues shifted. Concerns about the costs of fuel, the social and environmental impacts of transportation, and safety began to be traded off against the objective of simply increasing mobility. In the 1980s, additional problems will be added to those of the 1970s. Some of the problems will stem from growing international competition in the manufacture of automobiles and aircraft, some will come from international competition in freight transport, and some will come from current changes in the role of transportation in the life of Americans (NRC–16). All of those concerns present major challenges for the institutions associated with transportation in America, and science and, particularly, technology will contribute to meeting those challenges during the balance of the century.

This section focuses on three interrelated transportation problems that can be significantly affected by science and technology. A fourth area of concern, the international competitive position of American transportation industries, shares problems and opportunities with other science- and technology-based industries and, therefore, is discussed generically in Sections I–B and I–D and in more detail in the appended *Source Volumes* (NRC–14; NRC–16; AAAS–2; TRANS). The three problems to be discussed here are the need to meet the Nation's transportation requirements as they expand over the coming years, the need to respond to increasing constraints on liquid petroleum as an inexpensive and readily available energy source, and the need to accomplish those goals while increasing transportation safety.

It should be emphasized that the American transportation system is in fact multimodal, and the total system is in some senses greater than the sum of its parts. That means that choosing among alternate strategies to resolve problems—whether those strategies are technical, legal, or social in nature—requires an appreciation for and consideration of the complex interactions among the various transportation modes, while still recognizing the values and problems unique to each (NRC–16). For example, the advent of lightweight, energy-efficient automobiles has already had positive effects in reducing energy requirements. Additional energy efficiencies could result from an increase in truck payloads. But, carrying heavier payloads increases wear and tear on the highway system, much of which already is in need of repair, and it is not clear that lightweight automobiles can tolerate extended use on deteriorated roadways. Therefore, rehabilitation of much of the U.S. highway system using improved materials may be required before those two strategies for increasing energy efficiency can reach their full potential (TRANS).

DEALING WITH INCREASED CAPACITY REQUIREMENTS

All estimates indicate that transportation capacity requirements will continue to grow in the coming years, although that growth is expected to be slower during the rest of the century than in the immediate past. That growth, coupled with a variety of constraints, including limitations on carrying capacities and the need to increase transportation safety, requires the application of new science and technology developments to the U.S. transportation system.

EXPECTATIONS OF TRANSPORTATION NEEDS

In 1975, passenger transportation between cities in the United States amounted to 1,352 billion passenger-miles, or over 6,000 miles for every man, woman, and child. Intercity movement of goods totaled 2,066 billion ton-miles, averaging almost 10,000 ton-miles per person.[1] When all transportation is included, both between cities and within cities, the averages for 1975 came to 12,000 passenger-miles per person and 15,000 ton-miles per person, totaling 2,568 billion passenger-miles and 3,275 billion ton-miles. That demand is expected to grow. According to one set of estimates (Tables 1 and 2), in the year 2000 there will be 5,008 billion passenger-miles of travel and 5,550 billion ton-miles of freight transportation. That would be an average annual increase of 2.67 percent in aggregate passenger travel and a 1.89 percent average annual increase for total freight transportation. Assuming

Table 1—Passenger Miles Traveled
(in billions)

MODE	1975	1985	1990	2000
Highway [a]	2,369	3,247	3,637	4,400
Air	178	356	425	585
Rail	21	22	22	23
Total	2,568	3,625	4,084	5,008

[a] Highway mode combines automobiles, personal light trucks, two-wheel vehicles, recreational vehicles, and buses.

Source: R.E. Knorr and Marianne Miller. *Projections of Direct Energy Consumption by Mode: 1975–2000 Baseline*. ANL/CNSV–4. Argonne, Ill.: Argonne National Laboratory, 1979.

Table 2—Freight Haulage
(in billion–ton miles)

MODE	1975	1985	1990	2000
Highway [a]	534	820	946	1,210
Air	7	12	15	20
Rail	732	1,092	1,237	1,550
Water	1,047	1,481	1,597	1,730
Pipeline	905	1,037	1,131	1,040
Total	3,225	4,442	4,926	5,550

[a] Assumes commercial and government vehicles; excludes personal trucks.

Source: R.E. Knorr and Marianne Miller. *Projections of Direct Energy Consumption by Mode: 1975–2000 Baseline*. ANL/CNSV–4. Argonne, Ill.: Argonne National Laboratory, 1979

a U.S. population of 250 million, the per capita average would be 20,000 passenger miles and almost 21,000 ton-miles. Under that assumption, the average annual increase in per capita passenger transportation capability between 1975 and 2000 would have to be about 2 percent and that for freight transportation about 1⅓ percent over the next 20 years (NRC–16). Thus, while transportation is expected to continue to grow on a per capita basis, that growth is expected to be slower during the rest of the century than in the immediate past.

Alternatives to increased transportation capacity do exist. Increased decentralization of production into smaller, more self-reliant communities is one such alternative for reducing demand, thus decreasing capacity problems, and that possibility would be facilitated by expanding communications capabilities (*Outlook I*). But, since such changes are accomplished slowly and are measured in multiples of decades, transportation demands will almost certainly continue to grow during the rest of the century.

DEALING WITH CAPACITY LIMITATIONS

In the face of a need for increased transportation capacity, it also is likely that the entire U.S. transportation system will be encountering increasing limits on its carrying capacity during the next 5 years. For example, the highway system is already showing signs of wear (*Outlook I*). Programs for pavement resurfacing, restoration, rehabilitation, and bridge replacement have the potential to stem the problem. However, costs will be substantial, particularly because we are lagging so far behind in maintenance (TRANS). Ironically, the situation has been exacerbated by our success in improving the fuel economy of motor vehicles, since their increased use has led to a decrease in highway maintenance funds derived from fuel taxes.

Development of paving substitutes from nonpetroleum derivatives that will be competitive with asphalt and portland cement is a key area where research and development can contribute to highway improvement and maintenance. In addition, technologies for detecting highway flaws are a preventive alternative that could reduce maintenance costs and help relieve capacity constraints on the highway systems that are due to failures and repair and maintenance outages (TRANS).

Increasing highway congestion is another serious concern. Currently available control technologies can deal effectively with low concentration flows of highway traffic, but high-density congestion remains a problem. Alternatives are emerging, however, that could extend our capability to control highway congestion. One is the emerging technology of ramp metering signalization for highways. In the much longer term, more general automation of highway travel may become an effective flow control procedure both for reducing congestion and for improving safety.

Air transportation will also face increasing capacity problems during the next several years as traffic growth begins to reach airport capacity (NRC–16). The problem has been averted so far with the development of larger aircraft, but that approach is nearing its limit. One alternative solution is provided by current developments in advanced air traffic control, which will improve the productivity of the U.S. commercial air transport system (NRC–16; TRANS).

The success of various future energy strategies for the United States (see Section II–E) will require substantial modifications in the capacity of transportation systems to move energy sources. In particular, if the use of coal is to be greatly expanded—both for direct use and as a source of synthetic fuels—improvements will be required in its distribution modes. At present, rail, water barge, and trucking handle 63 percent, 11 percent, and 12 percent of the coal traffic in the United States, respectively, with other modes accounting for only 3 percent. (The remaining 11 percent of the coal is used for onsite power generation at mines.) Analysts believe that of those three transportation modes, railroads offer the best combination of flexibility and cost for domestic transportation. Anticipated needs for the next decade will, however, require a good deal of expansion in the carrying capacity of railroads in the West, and an expansion as well as an overall improvement in the quality of railroads in the East.[2] The use of slurry pipelines, in which crushed coal mixed with water is carried, offers an economically attractive alternative for rail transport for distances up to 300 or 400 miles. Available water may be a limiting factor, however, particularly in the Rocky Mountain West. Meanwhile, research is proceeding on the flow behavior of the coal-water mixture (ENERGY).

The movement of coal also requires traffic flows on the U.S. waterway system, which is constrained by capacity limits. In particular, our port systems are currently unable to handle the storing and loading of the volume of coal destined for ocean transport. That is a particularly important concern for the future, since the United States, with an estimated 30 percent of the world's coal reserves, could gain considerable trade advantage as an exporter of coal (NRC–16; TRANS).

Expanded use of natural gas is an attractive short-term alternative to oil in some applications, and prospects for increased domestic production in the lower 48 States during the next decade are considered reasonable (Section II–E). Those supplies could be augmented by transoceanic imports of liquefied natural gas, which is, however, highly flammable and could thus constitute a hazard at storage sites, processing facilities, and ports. In 1980, the Department of Transportation issued proposed regulations on the design, siting, construction, operation, and maintenance of liquefied natural gas pipelines and facilities (*ASTR–III*), and research aimed at facilitating transportation safety will be a continuing priority for the next 5 years (ENERGY).

IMPROVING TRANSPORTATION PERFORMANCE

Given projected needs for increased transportation capacity, coupled with the major constraints of projected decreased availability of conventional energy sources (Section II–E), major changes will be needed in the characteristics of transportation vehicles. In the short term, there will be a need to continue to increase the efficiency of energy use. In the long term, engines for transport vehicles will have to be redesigned to accept the variety of fuels that will make up future energy sources, and they may have to be able to function on mixes of fuel (NRC–16). Progress has already been made toward the former goal and will surely continue during the next 5 years.

INCREASING ENERGY EFFICIENCY

Transportation accounts for about 25 percent of national energy consumption and about 50 percent of petroleum fuel use. Thus, the most immediate requirement for improvement in all modes of transportation is increasing energy efficiency. By 1985, the greatest energy efficiency improvements are expected to occur in automobiles and commercial aircraft. New technologies that reduce vehicle weight—for example, substituting lightweight composite materials for heavier alloys (NS)—and that improve engine efficiencies can lead to a doubling of the energy efficiencies of those modes over 1975 performance. In addition, new vehicle designs can greatly aid fuel efficiency (NRC–16; NS). Beyond 1985, various options are possible. For example, the potential exists for development and widespread use of a two-passenger automobile, which, on an energy per passenger-mile basis, can meet or exceed the efficiencies of either bus or rail passenger transport. Additionally, emerging new technologies are expected to increase the fuel efficiency of aircraft—such as advanced turbo prop engines and new technologies for laminar flow control (NRC–16).

Conventional gasoline and diesel engines are expected to be improved in efficiency beyond 1985, but, in addition, there is extensive research directed toward the commercial development of alternatives to the conventional internal combustion engine (NRC–16). For example, both gas turbine and Stirling engines are receiving emphasis, and success in those efforts could lead to a significant increase in fuel efficiency over that of the best projected 1984 internal combustion engine (ENERGY). The systems might be available during the 1990s; it should be emphasized, however, that full-scale demonstration of automobiles with the new types of engines has not yet occurred, and that the capitalization costs required to mass produce such new cars would be enormous (NRC–16).

PREPARING FOR FUEL SUBSTITUTION

Of comparable importance to improved energy efficiency during the next 5 years are technologies for the production of new nonpetroleum fuels. The development of marketable technologies for extracting gasoline and diesel fuel from oil shale and for producing them as synthetic liquids from coal is well under way. Technology to produce methanol from coal for use in internal combustion engines is in a similar state. Liquid fuels from biomass are another possible, although more limited, resource. However, while those resources promise to provide the United States with transportation fuels for years to come, they will have little impact on our total needs for at least another decade (Section II–E).

Research has also been initiated on new batteries that would greatly increase the energy density of present lead-acid batteries. The latter provide very limited performance and are very expensive, and development of improved storage devices would provide the potential to use electrical energy generated from nonpetroleum sources as a major transportation energy supply (NRC–16). Furthermore, the possibility exists that buses and trucks, as well as automobiles, could be supplied energy by electricity. One possibility currently being explored is the transfer of power through magnetic flux from cables laid in highway pavement and requiring no contact between the roadway and the vehicle. Prototype experiments with that technology are now in progress (TRANS). As the price of petroleum continues to rise, such alternatives as those, and others to be developed, may be able to fill a significant portion of the fuel requirements for transportation and, thereby, relieve some of the pressures on the American social and economic systems. However, few if any of the developments are likely to reach fruition until well beyond 1985, although substantial progress should be evident by then.

IMPROVING TRANSPORTATION SAFETY

The current U.S. transportation network is enormous. Americans own more than 100 million automobiles that travel over nearly 4 million miles of roads. Scheduled airlines transport more than 300 million passengers annually. The U.S. rail system is the largest in the world, with more than 300,000 miles of track. It is projected that in the highway mode alone, however, more than 50,000 Americans will die in traffic accidents in 1981. Additionally, while motor vehicle fatalities account for the largest portion of transportation-related deaths, there also are losses due to air, rail, and water accidents (TRANS).

In choosing among options for future improvements in the transportation system, implications for safety will have to be one of the major underlying considerations. The safety of individual technologies can be assessed through a variety of scientific and technological means, and there will be increased needs for those kinds of assessments in the coming years (TRANS) (see also Section I–E).

It is worth noting that most technological effort has focused on postcrash survivability and injury reduction rather than on accident prevention. As the United States moves toward increased use of smaller vehicles, such strategies will become more costly and less effective. A good deal of information relative to automotive safety gains could come from human behavior studies (NRC–16). Additionally, two technologically oriented options now being explored primarily for nonhighway transportation that also could have fruitful implications for automobile traffic safety are described below.

The innovative use of radionavigation, radiolocation, radiocommunication, and computer systems provides opportunities for improving both the safety and the efficiency of air and water transportation by expanding the capabilities of and improving access to sophisticated navigation, warning, and traffic control systems. For example, with anticipated increases in air and water traffic, systems to provide both for specific coverage in highly developed geographical areas and for wide area coverage will be needed. Additionally, new developments in electronic communications and computer microprocessor technology are lowering the costs of and facilitating improvements in advance warning systems. New radar technologies soon will provide dramatic improvements in capabilities for detecting and issuing warnings about severe weather conditions and will also provide improved weather information for air traffic and surface vessel control (TRANS).

The convergence of computer and communications technologies may also provide opportunities for transportation safety improvements through automation. Some experience with such automated systems is already available in mass transit and air traffic control. Human operators cannot, however, be entirely eliminated from any control system, be it related to transportation, manufacturing, or power plant operation. Indeed, the training and skills required of human operators increase as control systems become more sophisticated. Therefore, human factors research to provide a better understanding about the interface between humans and machines may be one of the most important needs related to transportation safety (TRANS).

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I. Agriculture

The U.S. agricultural enterprise is a major contributor to the economic and social well-being of both this country and the world. It currently provides food for more people than ever before, while employing a constantly decreasing proportion of the labor force. For example, each American farmer now produces enough food for himself or herself and 59 other people, a significant rise from 29 in 1970 and just 6 in 1900 (AAAS–8). In addition, American agricultural products are a mainstay of the food supplies of many other countries. In fact, exports of agricultural products constitute over 20 percent of the total value of American exports, a situation that has clear short-term benefits (IA). However, the capacity of the American agricultural enterprise is limited. There could be long-term problems associated with the world's dependence—and our own—on American agricultural exports, including overexploitation of domestic land, water, mineral, and energy resources and rising domestic food prices. Therefore, in the long term, U.S. interests may be best served by increasing the worldwide distribution of food production activities, as well as by increasing the total productivity of world agriculture (AAAS–8; IA).

The agricultural enterprise, like many other areas of American life, is currently facing some significant problems, and the appropriate development and application of science and technology capabilities to those problems will be crucial. The most critical problems may be in agricultural productivity. While the productivity of agriculture has been increasing both in the United States and in other countries at a very high rate for the last half century, the rate of increase has recently begun to slow, suggesting that productivity increases could reach a plateau (AAAS–8; *Outlook I*). At the same time, population pressures, among other factors, will continue to place ever-increasing demands on worldwide food supplies (NRC–1; AAAS–8; AAAS–9).

To some analysts, the slowing rate of agricultural productivity growth suggests that current Western agricultural approaches, involving energy-intensive but labor-saving technologies, may be reaching the point of diminishing returns, and new approaches to agricultural endeavors need to be contemplated (AAAS–8). Continued attention to the development and implementation of a wide variety of new technologies, coupled with consideration of the social and economic aspects of the agricultural enterprise, will be needed over the next 5 years to permit the continued growth of American agricultural productivity. What follows are discussions of three aspects of the agricultural enterprise that contain special opportunities for science and technology to facilitate agricultural productivity growth. They concern (1) the input resources needed to support agriculture, (2) potential changes in crop yields, and (3) postharvest treatments. The final part of this section emphasizes interactions between the agricultural enterprise and other sectors of society.

Before discussing the opportunities and needs for scientific and technological development, it should be mentioned that changes in agricultural approaches always involve tradeoffs, or various ways of combining input and output factors. As in the breeding of plants and animals, where an increase in one characteristic, such as hardiness, typically is compensated for by decreases in another characteristic, such as yield, so the practice of agriculture trades off labor demands against demands for other resources, such as energy, water, fertilizers, and pesticides. The tradeoffs may be in physical terms, such as limits on real resources, or they may be in economic terms, such as price differentials. Thus, for example, water may be absolutely unavailable in some circumstances, but in other cases it may only be very costly. In many cases, it is not absolute limits but economic factors that constrain agricultural production (AAAS–8). Productivity is defined as "output per land unit, per time unit, per cost unit," and it can be influenced significantly by technological practices that affect any one or all of those components.

ENSURING ADEQUATE RESOURCES FOR THE AGRICULTURAL ENTERPRISE

One important set of problems and opportunities concerns the inputs to or resources for the agricultural (i.e., growing) process. Although there is a wide variety of inputs to agriculture, three are directly related to science and technology. They are land resources, water resources, and the supply of nutrients needed to sustain plant growth.

CONSTRAINTS ON THE AVAILABILITY OF LAND

The most basic of all resources for the agricultural enterprise is land, and unless there are some truly revolutionary changes in development policies and agricultural approaches, land availability will be a major limiting factor on agricultural productivity for decades. As land becomes increasingly valuable for other purposes, agricultural activities tend to be pushed toward less productive land. That phenomenon is most striking in the industrialized countries, but it is also beginning to be felt with increasing severity in the third world (IA). Thus, the use of less than prime land for farming and ranching in turn requires increased use of other resources, including water, fertilizer, and, particularly, labor, raising the costs of the process and lowering the return even further. In addition, the use of poor land for agriculture puts a high strain on that land, leading to very rapid soil degeneration and erosion. Cropping practices that rely on heavy use of monoculture, chemicals, and heavy machinery reduce the fertility and tilth of the soil even further. One way to counteract decreased adequacy of the soil is through a variety of soil conservation practices. However, the techniques of soil conservation, while generally understood, are still not practiced extensively even in the United States (AGR). Encourging soil conservation is one approach through which prompt policy attention might be highly effective over the next few years. Other issues concerned with land resources, particularly the problems associated with deforestation, are discussed in the Natural Resources section of this chapter.

THE PROBLEM OF WATER RESOURCES

The availability of water may prove to be an even more severe limiting factor in the development of agriculture in coming years (AAAS–8). In the United States, 80–85 percent of total fresh water use is for agriculture (by contrast, the production of food consumes only about 3 percent of the total energy used) (AAAS–8; *ASTR–III*). The issues of general water resource availability and water quality preservation are discussed in the Natural Resources and the Environment sections of this chapter, respectively; however, some points should be reiterated here.

Water as a resource is extremely variable in its distribution and almost impossible to transfer economically over large distances. Moreover, water is a particularly unpredictable resource. In much of the world, rainfall is never "normal," but varies greatly from year to year. Thus, a large burden on the agricultural system is to overcome some of the ups and downs in water availability, and the traditional approach has been to move water from place to place, such as in irrigation. That technique, however, can be very labor intensive, it consumes energy, and it can reduce both the quality and the quantity of water resources downstream. Therefore, water movement is a less than optimal solution to water shortage problems.

Several research directions are being followed in an attempt to provide alternative mechanisms for dealing with the water constraint on agricultural productivity. For example, new developments in irrigation, particularly in improving the efficient use of water through such techniques as drip irrigation, timing improvements, and use of such alternate energy sources as the sun and wind to power irrigation systems have much promise. Research is also being pursued in improving the efficiency of desalination and developing plant species that can be grown in high-saline water, thus expanding the potential for the use of increasingly brackish water supplies and direct use of sea water. Considerable progress in those areas is expected over the next 5 years (AGR).

PROVIDING ADEQUATE AMOUNTS OF NUTRIENTS FOR CROP GROWTH

The problem of nutrient supplies for agriculture, both through natural and synthetic fertilizers, is particularly critical, not only in this country but in many developing countries. The move of agriculture from prime land to less desirable land, as noted earlier, requires supplementing nutrient levels to compensate for the reduced levels of natural supplies in the less-than-desirable land. But the production of artificial fertilizers is also subject to tradeoffs. The primary source of nitrogen used in the United States to produce fertilizer is natural gas. As energy prices rise further, so will agricultural production costs. Moreover, the long-term effects of intensive reliance on synthetic fertilizers are unknown, particularly in the poor soils reclaimed from tropical forests for agricultural use (NRC–5; *ASTR–III*).

Scientific and technological advances can have significant impacts on the problems of providing adequate nutrients to support plant growth. Research is proceeding on several levels. On what has been called the macro level, experiments with multiple cropping, recycling of agricultural waste products, organic farming, and other changes in cultivation practices have shown some success (AGR; *ASTR–III*).

On the micro level, research in nutrient cycles is in progress. When ecosystems are disturbed, so too are the balances among nutrients that are shared throughout the food chain. Plants vary significantly in the relative efficiency of their nutrient intake processes, and an understanding of the factors that make for greater efficiency in nutrient uptake is just starting to emerge. That kind of research provides an opportunity for the eventual selective breeding of plants that can absorb and process much greater volumes of nutrients from the same basic source. Ultimately, research into mutually beneficial relationships among plants, such as those that exist between rice and certain types of algae, may improve the efficiency of plant nutrition significantly, thus improving yields without increasing the basic nutrient investment required (NRC–5). Those and similar lines of research present major opportunities for advances in supplementing nutrients as natural supplies diminish.

INCREASING PRODUCT YIELDS

The existence of current and potentially increasing constraints on the availability of resources for agriculture is cause for concern about the ability to increase agricultural productivity to the levels required in the future. Making optimal use of available resources is one approach to increasing productivity in the face of the problems. Another approach is to increase the yield of agricultural products grown under the resource-constrained conditions, and that increase can be accomplished in a variety of ways.

ALTERING PLANT AND ANIMAL STRAINS

Scientific and technological advances in recent years have opened a range of opportunities for improving crop strains and crop versatility. While selective breeding of agriculturally useful species is almost as old as human civilization, recent developments in molecular, genetic, and developmental biology have improved scientists' ability to understand how plants and animals function and grow. Therefore, there is the potential to engineer more deliberately further changes in the characteristics of plants and animals. The opportunity is partly the result of new developments in fundamental knowledge, partly the result of such new manipulation technologies as recombinant DNA and gene splicing. One particularly promising area for development is the creation of plants that can fix nitrogen biologically, either by themselves or with the aid of symbiotic bacteria, instead of relying on chemically fixed nitrogen, either natural or synthetic (NRC–17). Another is the possibility of developing synthetic versions of natural "growth regulators" that could speed the development of plants and animals. Changing the rates of development might shorten the time required for a crop to be ready for market, thereby increasing yields (AGR).

The cultivation of animal species is potentially as significant as the cultivation of plants. While it is sometimes asserted that animal culture is less efficient than plant culture in meeting total nutritional demand, nearly two thirds of the world's agricultural land is in pasture or range suitable for animals, and 60 percent of that land would not support the cultivation of plants (AAAS–8). Again, advances in scientific techniques, particularly in genetic engineering and embryological research, are now making and promise to continue to make significant contributions to increasing the effectiveness and efficiency of animal husbandry (AAAS–8; AGR).

CONTROLLING PESTS

In addition to developing new or modified agriculturally relevant plant and animal strains, controlling agricultural pests is a mechanism that can be invoked to increase product yields. The control of pests, whether they are plant, animal or microbial, is a critical aspect of the efficiency of agriculture. It is estimated that 30–40 percent of the world's crops are lost to disease between planting and harvest, and another 10 percent is lost in postharvest storage due to pests (NRC–6). Again, scientific and technological advances can help on several levels. On the epidemiological level, sophisticated analytical methodologies are being used to understand patterns of the spread of disease and the nature of biological susceptibility. On the farm level, integrated pest management (IPM) is gaining in use. IPM involves fitting together information about the biology of pests, the environment, and the status of the host to obtain maximal results from the application of biological (natural enemies, parasites, and predators) and chemical control methods. The technique not only reduces the load on the environment from pesticides, but is also cost-effective (NRC–6).

One approach used in IPM involves the selective use of "multilines," selectively bred variations of plants that are similar in yield but different in their relative resistance to diverse pests. The tendency in selective breeding, particularly of plant species, traditionally has been toward seeking greater genetic uniformity, standardizing yields but increasing the susceptibility to pests. However, there is no antibody response to infection in plants; disease resistance is purely an inherited trait and can only be conveyed genetically. Therefore, developing multilines can be used to slow the spread of such infections as wheat rust by decreasing the proportion of plants in a given area that are susceptible to particular varieties of the disease. The disease problem will never be completely solved; disease spread appears to vary according to the natural resistance offered by hosts and is continually changing, but, it can be controlled. Thus, constant attention to plant disease spread is needed (NRC–6). In providing that attention, however, it should be remembered that natural epidemics almost never occur; major plant diseases are the result of human transfer of plants from one biosystem to another. Therefore, understanding the nature of the systematic relationships of plants to their environments is a major aspect of the control of agricultural pests and will require additional activity in the coming years (NRC–6).

PREPARING FOR CLIMATIC AND ENVIRONMENTAL STRESSES

Environmental stresses other than pests and predators also threaten agricultural yields. There is no doubt that the world is undergoing some significant changes in climatic patterns, although the direction in which those changes are tending and the causes, whether they are natural or human induced, are still open to debate. The immediate effects are to upset patterns of cultivation by changing rainfall levels, temperature, and nutrient supplies. Those changes in turn alter yield patterns and, thus, aspects of the interrelationships of agricultural products, such as the availability of animal feeds. Work continues on using genetic engineering techniques to "climate-proof" plants and animals, improving their ability to withstand environmental stresses. That approach could not only reduce the exposure of plants and animals to normal hazards, but could also expand the range of lands in which cultivation is possible (AGR).

In the long term, the effects of climatic changes may be even more dramatic than they are currently. For example, continued burning of fossil fuels and the conversion of tropical forest to agriculture, as discussed in the Natural Resources section of this chapter, is likely to have major effects on carbon dioxide levels in the atmosphere (NRC–5). Such other stresses as pollution, particularly the "acid rain" that results from the use of fossil fuels, affect the biosphere and hence agriculture in key ways (AGR; ENVIRON). Much remains to be learned about precisely what the effects of such stresses and changes on agriculture are likely to be and how they might be alleviated. The lack of knowledge raises the need for additional scientific and technological efforts directed toward, first, identifying the potential problems and, second, devising counteractive measures.

GETTING AGRICULTURAL PRODUCTS TO MARKET

A major but generally disregarded aspect of efficiency in agriculture is the processing and distribution system. Postharvest losses in the United States cost an estimated $30 billion annually, and in some developing countries losses of over half of the harvested crops have been reported (AGR). The transporting and processing of food account for two thirds of the final price of the food to the consumer. Activities in this area are complicated by a lack of knowledge about what processing does to the nutritional content of food and its ability to supply the nutrients to the consumer. Thus, the development of improved methods for storing, distributing, and processing food is badly needed.

Two main directions are now being pursued. The first deals with ways in which food preservation can be enhanced, and techniques being studied include irradiation, improved sealing, better detection mechanisms for contaminants, atmospheric control, and using better combinations of ingredients. The second concerns distribution mechanisms involving transportation and improved access of the consumer to the producer. Clearly, postharvest technology development has strong potential for improving agricultural efficiency and productivity (AGR).

INTERACTIONS WITH OTHER SECTORS OF SOCIETY

This section began by noting that agriculture is characterized by tradeoffs at all levels. Those tradeoffs go beyond agriculture; frequently there are global tradeoffs between the agricultural system and other societal activities. Competition for such resources as land, water, and energy have already been mentioned. Additionally, there is predicted to be a potentially severe shortage of persons with selective agricultural training in the near future (AGR). Competition also includes such aspects as the diversion of agricultural products to nonfood uses, such as the use of corn and other biomass for fuel production and the use of vegetable oils directly as fuels (ENERGY). It involves the tradeoffs between agricultural demands and the requirements for environmental security. The runoff of fertilizers is a major cause of water pollution, for example, and dealing with such sources of pollution will clearly affect the efficiency of agriculture (NRC–7; ENVIRON). The tradeoffs or balances between the needs of different sectors will become more and more important in policy decisions in coming years as resources become scarce and such other concerns as the quality of the environment constrain agricultural activities.

Ultimately, agriculture must be viewed as a social and economic system as well as a biological system. For example, tax and regulatory policies adopted to deal with other social problems will clearly affect agriculture as well. Understanding the economic and social relationships of agriculture with society, in both this country and abroad, will require the involvement of social scientists as much as plant geneticists and computer modelers. Thus, in agriculture, as in the rest of science and technology, a unified and multidisciplinary perspective on both the basic scientific and policy issues will be essential (AAAS–8).

J. Education

Science and technology and education are intimately linked. Not only are science, mathematics, and technology significant components of the curriculum at all educational levels, but, in addition, science and technology provide powerful tools that are broadly applicable in the educational process itself. As an example in the latter case, recent advances in computer and communications technologies and in cognitive science and related disciplines offer major opportunities for improving educational strategies. However, before that knowledge can be widely applied in the classroom, several critical problems need to be resolved, and many of the problems are too complex for resolution by any single sector of society. Therefore, during the next 5 years, attention will need to be focused by State and local governments and by the private sector on ways to foster cooperation among private industry, State and local jurisdictions, and college and university science and engineering departments to take full advantage of the opportunities offered to the educational system by science and technology, and to resolve problems associated with their use in the educational process.

There is also a range of problems associated with the first aspect of the relationship mentioned above, that of education in science and technology, that will need to be addressed in the next 5 years. The need for an adequate supply of well trained scientists and engineers for the Nation in the long term has been treated in Section I–B. In addition, there is a need to improve the training of technicians that provide support for the work of scientists and engineers. Furthermore, since many other professions and occupations that formerly had little scientific or technical content now require a moderate level of competence in those areas, and since numerous public policy issues have significant science and technology components, an improved level of understanding of science and technology among the general public is becoming increasingly desirable.

USING THE OPPORTUNITIES PROVIDED BY SCIENCE AND TECHNOLOGY IN THE EDUCATIONAL PROCESS

There are new demands on the educational system to prepare all segments of society to use technological information and products, and science and technology can provide a means to update our educational system to meet those and other needs. Information-handling and computer technologies, and the cognitive sciences, provide special opportunities over the next 5 years to enrich the learning process, both through the application of recent basic research findings and through the utilization of new technologies (NRC–4; EDUC). However, there are several major factors that can inhibit their incorporation into our formal educational system. Therefore, the process of transferring the varied research findings and new technologies into the classroom will require concomitant attention and action (EDUC).

THE OPPORTUNITY PROVIDED BY INFORMATION TECHNOLOGIES

Computer-based learning devices and communications technologies can provide the basis of effective and efficient strategies for classroom teaching by, for example, offering means for individualized, interactive instruction and for more sophisticated performance testing and evaluation. Of course, some use has been made of teaching machines for many years in language classrooms and in undergraduate science courses. In addition, those technologies are being used extensively in training military personnel (NS). However, examination of the overall school curriculum reveals little evidence of the impact on education of the contemporary electronics revolution that, by radically altering the ways business and industry are conducted, is changing the nature of many jobs. For example, there are suggestions that the ability to use computers may be judged a basic skill in the future, but there presently does not exist a recognized curriculum for teaching computer skills or a system for measuring competency.

Advances in computer technologies include expansions in disc storage capacity, easy access to stored information, sophisticated visual displays of information in a variety of formats, and audio tracks and computers that can simulate the human voice. Furthermore, in recent years, both the size and the cost of computer hardware have been reduced substantially, and its portability has increased significantly. Handheld calculators with a variety of functions now sell for between $10 and $100, and electronic games that teach mathematics and spelling retail for about $65. Personal computers with a visual display and memory and weighing less than 50 pounds now cost as little as $400. They are comparable to computers that cost more than $100,000 15 years ago, and future costs are expected to remain constant while the computational power of the computer is expected to double every 2 years (EDUC). Recent trends in cost reduction and augmentation of computer performance are shown in Figures 5 and 6, respectively.

The new developments open up a wide range of possibilities for innovative instructional activities and procedures. As such, they have the potential for adapting

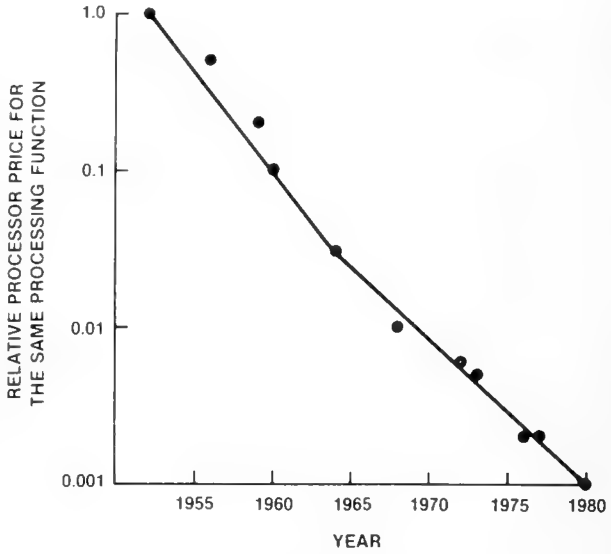

FIGURE 5. Relative Computer Processor Price.
Source: D.P. Kenney. *Microcomputers*. New York: AMACOM, 1978.

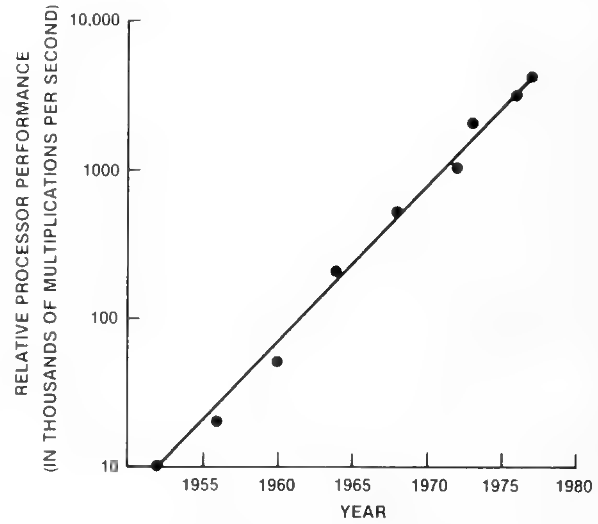

FIGURE 6. Relative Computer Processor Performance.
Source: D.P. Kenney. *Microcomputers*. New York: AMACOM, 1978.

educational strategies and curricula to a range of local requirements. Operator-controlled computer simulation and graphic displays of objects can allow exploration and training in a variety of complex skills. Instruction with computer games could increase student interest and, therefore, learning, while word processors coupled with computerized dictionaries can aid the development of writing skills. Computer-based testing can aid evaluation of a student's problem-solving skills as well as his or her knowledge of material and can provide guidelines for improvement. The new technologies can also expand our access to information, including historical, cultural, and artistic resources; still and motion pictures; library catalogs; and, eventually, even the texts of journals and books (EDUC; *Outlook I*).

The technologies can also help increase educational opportunities for physically handicapped individuals. Persons who are paralyzed or have limited muscle control can use special computer keyboards or other robotic functions to participate in writing, problem solving, and design activities. Visual information can be transformed into surface textures for the blind. Words and numbers can be converted into synthesized speech. Similar devices can be prepared for other handicapping conditions (EDUC).

In summary, the new computer and information technologies provide dramatic opportunities for improving student motivation, concentration, and comprehension, and they allow for individualized instruction based on differing rates and styles of learning. The increased use of the technologies in the classroom would also prepare students to utilize them more effectively, both in their personal lives and in future occupations and professions (EDUC). However, realizing those potential opportunities has not historically and will not in the future be a simple process. It will require concerted and directed action in the coming years to foster the widespread acceptance or use of the technologies.

THE PROBLEM OF TRANSFERRING TECHNOLOGY INTO TEACHING SITUATIONS

Transferring technology into the classroom can be quite complex and multifaceted. For example, there is the problem of cost. On one hand, reductions in the prices of the new computer and information-handling technologies make hardware itself more accessible to schools. Positive effects on student motivation and learning, as well as the ability of the new technologies to address the educational needs of special populations, might also lead to indirect cost savings by increasing the effectiveness of educational processes. On the other hand, none of the technologies is likely to be effective in the absence of efforts by State and local agencies to restructure curricula, revise textbooks, develop special software, and revamp teacher training and retraining programs. Furthermore, the technologies are rapidly advancing, and there is the danger that once they are installed and particular programs are initiated, they will soon become obsolete. Therefore, the tradeoffs between short-term costs and long-term costs and benefits will have to be carefully assessed. In addition to the balance between costs and benefits, there are other institutional problems and opportunities that will have to be addressed. They include clarifying and reevaluating basic educational strategies by State and local governments.

Clarifying the Role of the Federal Government

Widespread interest in pursuing the applications of new educational technologies and related research findings has been expressed by State and local education authorities, publishers, and private industry. That interest was reflected in part in congressional hearings held in 1978 and 1980, in which participants agreed that new advances in science and technology can have significant influences on teacher effectiveness and on student learning. Participants in the hearings urged the various government agencies to assist the school systems in realizing the benefits from those opportunities. Additional support for using the technologies in education has come from the Office of Technology Assessment, which is studying the impact of the technologies on the educational process (EDUC). However, any response to those recommendations must recognize the primacy of State and local jurisdictions over public education.

The Need for Changes in Educational Approaches

The full potential of computer and information-handling technologies in the classroom cannot be realized in the absence of a significant restructuring of educational strategies and methods. However, any such restructuring implies a need for additional teacher training (or retraining), an expansion of laboratory facilities, and further curriculum development (EDUC; *ASTR–III*). More generally, the classroom teacher is a key factor in the success of any new educational innovation. But, there is currently a serious shortage of mathematics and physical science teachers in the secondary schools, with little prospect of early improvement in the situation, and those hired to fill the vacancies often lack the technical background to offer quality instruction even with existing curricula (*ASTR–III*). Other factors that could inhibit the implementation of the new technologies in the classroom include inadequate laboratory facilities and equipment (partially caused by rapid advances in science and technology) and a decline in programs for faculty development coupled with limited continuing education opportunities.

Fostering Industry Involvement

The process of adapting new electronics technologies to classroom use might be well served by increasing the participation of business and industry. The private sector has sophisticated knowledge of the new technologies and may be able to help in adapting the technologies to the classroom and in curriculum development. Other forms of industry support might include equipment, financial aid, and participation in teacher training activities. There are obvious benefits to industry, including the purchase of equipment and services by State and local governments and school systems. Industry involvement might also increase public support for its own research and development efforts. An equally important benefit is the opportunity to expose students to careers in science and technology, especially in those fields with shortages of trained personnel, as discussed further on in this section. Therefore, increasing indusry involvement is a potential mechanism for facilitating the technology transfer process in the coming years, and it would benefit both the educational system and the industries involved.

OPPORTUNITIES PROVIDED BY THE COGNITIVE SCIENCES

A central question concerning the use of new technologies in education is how students (particularly young children) respond to electronic teaching and learning tools. Cognitive science, a multidisciplinary approach to the study of human mental processes, may be able to shed some light on that and related questions. The relatively new field encompasses contributions from a number of disciplines, including psychology, computer science, anthropology, linguistics, and education. Current research addresses information processing, the storage and retrieval of knowledge, and the acquisition of cognitive skills. Notable recent advances in theory development include the use of mathematical models of decision processes, which allows scientists to distinguish the impact of human biases and discriminative capacity on task performance; the analysis of speech perception and the cognitive processes involved in reading; and the analysis of semantic memory and the correlates of recall of related words and concepts. Of particular importance for education is the aspect of cognitive psychology that focuses on the diagnosis of disabilities. That improved diagnosis would aid the education of the many handicapped school-aged children in the country who are mentally retarded, have speech defects, or exhibit learning or reading problems (NRC–4).

Other research findings in cognitive science also are directly applicable to education. For example, research in the problem solving process can offer more effective methods for teaching. The subdiscipline of psychology called metacognition is studying self-monitoring and self-control skills used in comprehension and complex knowledge acquisition. Teaching children to monitor their own comprehension, a characteristic of skilled readers, can be a powerful instructional technique (NRC–4; EDUC).

Effective human interaction, including that occurring in an educational setting, is partially dependent on one's ability to understand the feelings and intentions of others. Therefore, research on social and cognitive development of children can offer additional insights into the learning process, which could aid teachers in the presentation of material. Studies have explored the development of ethical sensitivity, the influence of peers, the process by which social and cognitive skills are learned, and the influence of television on behavior. In addition, some researchers are analyzing social and cognitive development in emotionally disturbed and delinquent children (SSRC–6).

The findings from these kinds of studies may be applicable in educational settings, although the exact way they might be applied has not yet been clearly articulated. One possibility noted above is that the studies could provide guidelines for the utilization of the new information technologies through the assessment of factors influencing modes of interaction. Future research could study the response of children to machine technology as a learning tool supplementing or replacing, in some instances, direct teacher-student interaction. A related investigation would be the effect of machine technology on social and cognitive development (SSRC–6).

PROVIDING ADEQUATE EDUCATION IN SCIENCE AND TECHNOLOGY[1]

A central concern with science and technology education is the ability of the United States to produce and maintain a pool of highly qualified scientists and engineers. There are now and may continue to be personnel shortages in several engineering specialties and the computer sciences, as well as spot shortages in important subdisciplines of the physical and biological sciences (*ASTR–III*). Since the impacts of those shortages are discussed in detail in Section B of the first chapter of this report, they will not be repeated here.

However, providing adequate education for future scientists and engineers is only one concern. The educational needs of two other larger groups will also continue to demand attention and action in the next 5 years. The groups are: (1) those who directly support the activities of scientists and engineers and/or whose jobs demand day-to-day familiarity with modern technology; and (2) the general public, many of whose occupations and professions increasingly involve science and technology considerations or dealing with technical people, and all of whom need some understanding of science and technology to function as citizens in a democratic society.

ENSURING AN ADEQUATE SUPPLY OF TECHNICALLY QUALIFIED PERSONNEL

Many people, including both administrators and technical staff, augment and support the work of science and engineering professionals. A moderate level of competence and understanding of science, mathematics, and technology has also become essential, or at least highly desirable, for effective performance in many professions, such as law or business administration, which had little to do with science and technology as recently as 20 years ago. A basic understanding of technology also can be useful for secretaries who use word-processing machines, grocery clerks who use automated checkout devices, and department store personnel who use computers to scan inventory. One area where there is a marked need for personnel with some fundamental understanding of science and technology is the armed forces. Weapons systems are becoming more and more sophisticated, and, although much of the training needed to function effectively in the armed forces is provided by the military, a background understanding of science and technology can be of great help (NS).

The technicians who work directly with science and engineering professionals or with their equipment (for example, repairmen, programmers, and laboratory assistants) are of particular concern, since the size and expertise of that group of specialists bear directly on the success of science and technology enterprises. Other industrialized countries, including West Germany, Japan, and the Soviet Union, provide specialized training, financially rewarding jobs, and high status to technicians. In contrast, American educational efforts in that area have been widely scattered among technical and vocational high schools, on-the-job training, and high-quality, although also high-cost, programs in the armed services. Recently, 2-year community colleges have begun to play an important role in technician training, and one important characteristic of those institutions is their sensitivity to local demand. However, they are at present overburdened with the need to teach remedial mathematics to entering students who lack an adequate preparation to pursue technical training courses, and are, in general, isolated from the rest of the science and engineering education system. Furthermore, little information is available to secondary school students about opportunities for careers in technical fields that exist for graduates with adequate preparation in science and mathematics or with state-of-the-art training in them. Finally, information is lacking about the present and future requirements of technology-based industries for technicians. Therefore, there is a need to obtain and assess information about the quality and extent of current technician training efforts and the present and future requirements for technical personnel.

EXPANDING PUBLIC AWARENESS AND UNDERSTANDING OF SCIENCE AND TECHNOLOGY

Most Americans have no direct involvement in science and technology or with science or engineering professionals. Yet, technological advances shape the quality and direction of all of our lives in such areas as health, employment, housing, recreation, family structure, and the general physical environment. During the remainder of the century, science and technology will likely increase the complexity of society, as they have during the past 20 years. Thus, a deeper understanding of science and technology and their relationships to society will be increasingly important to the ability of Americans to function both in their occupations and professions and in their roles as citizens.

Secondary school education in many industrialized countries, including West Germany, Japan, and the Soviet Union, places heavy emphasis on science and mathematics. On the other hand, while there is an increasing need for technological sophistication among the American public, there is indication of a trend during the past 20 years in the opposite direction—toward a decreasing understanding of even the rudiments of science and technology (labeled scientific and technological illiteracy by some). Purported causes of that trend include a declining emphasis on mathematics and science in secondary education, a shortage of qualified secondary school mathematics and physical science teachers, a reduction in requirements for college admission, and a lowering in the level and substance of courses at both secondary and college levels for students who do not pursue careers in science and engineering (*ASTR–II; ASTR–III*). Furthermore, given the rapid rate of technological advance during the past 20 years, many adults who may have received an adequate formal education in science and mathematics now find that education obsolete, unless they have taken advantage of informal opportunities to renew and refresh it (EDUC).

One potential consequence of the lack of scientific and technical sophistication among the general public, in addition to deficiencies related to professional and occupational needs, is a reduced ability to participate in the political process in an informed way, particularly in decisionmaking concerning science and technology policies and related activities. For example, it is useful for citizens to be able to understand, at least in a general way, analyses of costs, risks, and benefits associated with technological advances that have immediate impact on their lives (EDUC).

Since the decline in science and technology literacy among the American public has been evident for over a decade, and since its causes are complex, a variety of steps will be necessary to arrest and reduce it. None of them is likely to produce rapid, dramatic changes. The most important priority is to recognize the severity and complexity of the problem and to initiate long-term programs that can begin to have effects. The Federal Government's role in helping secondary schools and colleges provide more appropriate opportunities to study science and mathematics is necessarily limited (EDUC; *ASTR–II*).

REFERENCE

1. This discussion draws heavily on: U.S. Department of Education and National Science Foundation. *Science and Engineering Education for the 1980s and Beyond*. Washington, D.C.: U.S. Government Printing Office, October 1980.

Appendices

Appendix A

Notes on Using the *Five-Year Outlook* and Its Sources

The *Five-Year Outlook* on science and technology is not intended as an exhaustive treatment of all the issues associated with a given topic. Rather, it highlights those aspects that the National Science Foundation (NSF) considers most significant. Readers are referred to the *Source Volumes*, to sources contributed to the first *Five-Year Outlook*, and to recent *Science Indicators* and *Annual Science and Technology Reports* for more exhaustive, indepth discussions, as well as supporting evidence and argument.

The context of the legislation requiring the *Five-Year Outlook* and *Annual Science and Technology Reports* (Public Law 94–282) indicates recognition by Congress that the types and organization of the information in the reports should serve the needs of other audiences in addition to the policy planners in the legislative and executive branches of the Federal Government. In particular, the act addresses the need to exchange scientific and technical information among the various Federal departments and agencies. It also states, as a matter of policy, that the perspectives and needs of State and local governments, industry, universities, professional societies, and the general public should be taken into consideration in devising and assessing strategies for science and technology [Section 102(a), (b) and (c)].

Readers in each of those groups may, however, approach the *Five-Year Outlook* and its companion *Annual Science and Technology Reports* from different perspectives and with different objectives in mind. Those whose interests focus primarily on current and likely future developments in a particular field of science and technology, on particular science and technology policy issues, or on perspectives of a particular group of Federal science and technology agencies may want to proceed directly to relevant contributions published in the *Source Volumes*. For the convenience of such readers, an annotated bibliography of selected sources and a detailed topical index are included in the second *Source Volume*.

Readers who are interested primarily in current and emerging issues associated with particular Office of Management and Budget (OMB) functional categories can begin with the appropriate sections of Chapter II and refer to the sources cited therein for more extensive discussions of topics. Those who are concerned primarily with an overview of the relations of science and technology to broad areas of current national interests can begin with the four generic policy sections of Chapter I, again referring to the cited source references for more detailed discussion.

There are many other ways of presenting the material in Chapters I and II. An alternative, for example, would be to present a synthesis of the source materials categorized according to the 13 priority goals for science and technology listed in Section 102–(b) of the National Science and Technology Policy, Organization, and Priorities Act of 1976. Table 1 is intended to assist readers who require information about the relations between current trends and those 13 goals by identifying sections in the first and second *Five-Year Outlooks*, the first three *Annual Science and Technology Reports*, and the two most recent *Science Indicators* reports that address each goal.

Table 1—Sections of Some Related Science and Technology Policy Reports Discussing Priority Goals for Science and Technology.

PRIORITY GOALS	*SI-78**	*SI-80**	*ASTR-I***	*ASTR-II+*	*ASTR-III+*	*Outlook I°*	*Outlook II+*
1. Foster international peace, and other international and foreign policy goals	Ch. 1	Ch. 1	Ch. 5	III–H IV–A V	I–F II–E,L III–A	SOD–5	I–B,C,D II–C,D,E,F,G,I
2. Increase the efficient use of essential products and materials	pp. 55–60 pp. 81–83 pp. 93–99	pp. 60–69 pp. 79–82 pp. 179–200	Ch. 2 Ch. 3	IV–A	I–C II–E,G III–A	SOD–1,2,3 TS–1,2	I–C II–B,C,E,F,G,H,I
3. Assure an adequate supply of food, materials, and energy	pp. 55–60 pp. 93–99	pp. 60–64 pp. 79–82 pp. 97–99 pp. 115–116 pp. 190–200	Ch. 2 Ch. 3	II–C,E III–B,E IV–A IX–C,J	I–D,E II–E,G,H,J,L III–A	SOD–1,2,5 TS–2,4,5	I–D II–E,F,G,H,I
4. Contribute to national security	pp. 55–60	pp. 60–64 pp. 79–82	Ch. 2 Ch. 3	III–H	II–B	TS–7	I–B,D II–B,C,J
5. Improve health care	pp. 55–60	pp. 60–64 pp. 79–82 pp. 92–94 pp. 97–99 pp. 190–197	Ch. 2 Ch. 3	III–A IV–A IX–I	II–D,H,J III–A	SOD–3,4 TS–3,5,6,8	I–E II–B,D
6. Preserve, foster, and restore a healthful and esthetic environment	pp. 55–60 pp. 98–99	pp. 60–64 pp. 79–82	Ch. 2 Ch. 3	II–F IV–A IX–D	II–D,E,G,H,L III–A	SOD–3 TS–1,6,8	I–D,E II–D,E,F,G,I
7. Provide protection for oceans and polar regions; utilize their resources effectively			Ch. 3	III–E IV–A V–B	I–E II–L	SOD–5 TS–2	I–D II–C,E,F
8. Strengthen the economy and promote full employment through S&T innovations	Ch. 4	pp. 22–34 pp. 200–204 Ch. 4	Ch. 5 Ch. 6	II–B IV–A VIII	I-B,C	SOD–1,5,6 TS–5,7	I–B,C II–F,G,H,I
9. Increase the quality of educational opportunities	pp. 55–60	pp. 6–7 pp. 60–64 pp. 186–190	Ch. 2 Ch. 3	VI	I–B II–K	SOD–6	II–B,J
10. Promote the conservation and efficient use of the Nation's natural and human resources	pp. 55–60 pp. 93–99 Ch. 5	pp. 60–64 Ch. 5	Ch. 2 Ch. 3 Ch. 6 Ch. 7	II–F III–C,E,I IX–C	I–B,E II–B,C,G,J,L III–A	SOD–2,5 TS–1,2,4,5	I–E II–B,C,E,F,G,H,I,J
11. Improve housing, transportation, and communications systems; provide effective public services	pp. 55–60 pp. 93–99	pp. 60–64 pp. 79–82 pp. 200–204	Ch. 2 Ch. 3	III–D	I–D II–C,E,I III–A	TS–3	I–E II–B,C,D,H.
12. Eliminate air and water pollution, and unnecessary, ineffective, or unhealthful drugs and food additives	pp. 55–60 pp. 93–99	pp. 60–64 pp. 79–82 pp. 197–200	Ch. 2 Ch. 3	II–F III–C	II–D,G,H,J,L III–A	SOD–3 TS–5,6,8	I–D,E II–D,E,F,G,I
13. Advance the exploration and peaceful uses of outer space	pp 55–60 pp. 93–99	pp. 60–64 pp. 79–82 pp. 92–94 pp. 182–186	Ch. 2 Ch. 3	II–D III–G	I–F II–B,C,L III–A	TS–4	I–D II–B,C,F

*by chapter and/or page numbers
**by chapter number
+by chapter—section

°SOD = Statement of the Director of NSF—section number
TS = Topical Synthesis—section number

Appendix B
Preparation of the *Five-Year Outlook*

There are many centers of decision on the allocation of resources to the support of science and technology in the United States and on the use of the results of science and technology for a variety of public purposes. Hence, the National Science Foundation (NSF) decided at an early stage that each *Five-Year Outlook* should draw upon a broad range of perspectives, both inside and outside the Federal structure. Accordingly, the first *Five-Year Outlook* on science and technology, transmitted to Congress in May 1980, synthesized and highlighted detailed treatments of selected developments and issues contributed by the National Academy of Sciences, 21 Federal agencies, and 15 individual specialists in specific science and technology policy topics.[1] Those contributions were published in a separate source volume. Publication of the highlights and the more detailed source contributions in two separate volumes represented a compromise between the expressed needs of Congress for a relatively brief summary of significant trends and issues, and the desirability of providing more exhaustive documentation of specific topics for readers who wish to assess the supporting arguments and evidence relating to conclusions set forth in the summary.

The second *Five-Year Outlook* similarly draws on a range of sources and makes a similar compromise between brevity and comprehensiveness. The nature of the contributions and the ways in which the information they provide has been synthesized differ, however, from the first *Five-Year Outlook*. These differences reflect, in part, comments and suggestions made by readers of the first *Five-Year Outlook*, views expressed at three congressional hearings,[2] a symposium at the 1981 Annual Meeting of the American Association for the Advancement of Science,[3] and extensive evaluations by the five university science, technology, and public policy groups listed in Appendix C.

The design and content of the *Five-Year Outlook*, particularly selection of the four generic topics of Chapter I and the issues highlighted in both chapters, incorporates the continuing advice of consultants representing universities, industries, and State and local governments, and the results of discussions with representatives of several Federal agencies, including the Office of Science and Technology Policy (OSTP) and the Office of Management and Budget (OMB).

Responsibility for designing and preparing the *Five-Year Outlook* on science and technology was assigned to the staff of the NSF Office of Special Projects:

Dr. William A. Blanpied
Dr. Alan I. Leshner
Ms. Maeve McCarthy
Ms. Minerva Reid.

Liaison with other units of NSF was provided by an Interdirectorate Advisory Group:

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Dr. Marta Cehelsky, Office of Planning and Resource Management
Dr. Judith Coakley, Directorate for Engineering
Dr. Frank Eden, Directorate for Astronomical, Atmospheric, Earth and Ocean Sciences
Dr. Richard Louttit, Directorate for Biological, Behavioral and Social Sciences
Dr. Richard Nicholson, Directorate for Mathematical and Physical Sciences
Dr. Robert Rabin, Directorate for Biological, Behavioral and Social Sciences.

Individual sections of the *Five-Year Outlook* were prepared with the assistance of NSF's Division of Policy Research and Analysis. Sections were reviewed by technical experts inside and outside the Federal Government, and a revised manuscript was reviewed at a meeting of technical experts on April 9–10, 1981. Assistance in compiling quantitative material was provided by NSF's Division of Science Resources Studies. The final manuscript was reviewed by the Executive Office of the President prior to transmission to Congress. Individuals outside NSF who assisted in the design, preparation, and review of the *Five-Year Outlook* are listed in Appendix C.

The materials published in the two *Source Volumes* were reviewed and revised by their respective contributors prior to submission to NSF. Each of the chapters contributed by the National Research Council (NRC) was reviewed by specialists selected by the NRC, and the entire set of chapters was reviewed by the NRC Governing Board.

Drafts of the papers written for the American Association for the Advancement of Sciences' Committee on Science, Engineering, and Public Policy were reviewed at two invitational seminars. The reviews also provided the framework for broader discussions incorporated into two additional essays transmitted to NSF with the revised papers. Papers prepared for the Social Science Research

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[1] *Five-Year Outlook: Problems, Opportunities and Constraints in Science and Technology*, National Science Foundation: Washington, DC 1980. In two volumes (NSF Publications 80–29 and 80–30).

[2] June 13, 1980: Subcommittee on Science, Research and Technology of the House Committee on Science and Technology; July 31, 1980: full House Committee on Science and Technology; September 19, 1980: Subcommittee on Science, Technology and Space of the Senate Committee on Commerce, Science and Transportation.

[3] AAAS, *Program of the 147th National Meeting* (January 3–8, 1981). p. 107.

Council were reviewed by individual specialists, and the entire set was subsequently reviewed by a steering group including representatives of the Council, the Assembly of Behavioral and Social Sciences of the National Academy of Sciences, and the Center for Advanced Study in the Behavioral Sciences.

The 11 Federal agency papers published in the second *Source Volume* were drafted by representatives of 22 Federal agencies who worked together in task groups convened by NSF. Each agency with a science- and technology-related mission within a given functional area provided draft material to the group, and the contributions were integrated by a designated lead agency representative into a single draft narrative. This procedure was meant to provide as comprehensive a view as possible of interactions among Federal science and technology agencies with responsibilities in the same broad areas. Lead agency drafts were revised, prior to final transmission to NSF, in the light of comments by staff of OSTP, OMB, and NSF. Participating agencies were:

- Department of Agriculture
- Department of Commerce
  - National Bureau of Standards
  - National Oceanic and Atmospheric Administration
- Department of Defense
- Department of Education
- Department of Energy
- Department of Health and Human Services
  - Alcohol, Drug Abuse, and Mental Health Administration
  - Centers for Disease Control
  - Food and Drug Administration
  - National Institutes of Health
- Department of Housing and Urban Development
- Department of the Interior
- Department of Labor
  - Occupational Safety and Health Administration
- Department of State
- Department of Transportation
- Agency for International Development
- Consumer Product Safety Commission
- Environmental Protection Agency
- National Aeronautics and Space Administration
- National Science Foundation
- Nuclear Regulatory Commission
- Veterans Administration

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