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ABSTRACT

Produced in response to the Science and Technology Policy Organization and Priorities Act of 1976, this two-volume publication was written to provide a look into the future in terms of relating the agenda of science and technology to the visible near-term problems of American society and its external responsibilities for stable peace and the improvement of the human condition. Volume I is composed of the National Science Foundation's synthesis of the contributions to the project. Six issues are discussed at length: (1) stimulating innovation and productivity in industry and agriculture: (2) ensuring adequate supplies of energy and nonrenewable resources: (3) improving the science and technology base for risk assessment: (4) contributing to improvements in health: (5) maintaining international leadership in science and technology: and (6) ensuring the continued vitality of the nation's scientific and technological enterprise. (Author/PB)

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the Five-Year Outlook:

Problems, Opportunities and Constraints in Science and Technology

volume I

National Science Foundation

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LETTER OF TRANSMITTAL

NATIONAL SCIENCE FOUNDATION
WASHINGTON, D.C. 20550

OFFICE OF THE
DIRECTOR

MAY 12, 1980

To the President and Members of Congress:

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

In addition to materials written and compiled by the staff of the National Science Foundation, I have prepared a personal statement reviewing several important opportunities for science and technology to contribute to the solution of major national issues. All these issues involve public policy choices that will have to be made within the next five years and which deserve wide discussion. I believe this *Five-Year Outlook* can help facilitate such discussions in the Executive Branch, the Congress and throughout the Nation.

Respectfully,

R. C. Atkinson

RICHARD C. ATKINSON
Director

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Statement of the Director of The National Science Foundation

The first effort to prepare a *Five-Year Outlook* on science and technology has been a considerable challenge. The object was to capture perspectives, not to produce a catalog. The idea was to look *ahead,* not backward. Though the glimpse of the future was defined to be a five-year period, the processes of research and development hardly obey such discipline. The temporal constraint, therefore, had to take the form of relating the agenda of science and technology to the visible near-term problems of American society and its external responsibilities for stable peace and the improvement of the human condition. This task was not amenable to ivory tower meditation. It required wide participation, and we have gained a great deal by calling upon the National Academy of Sciences, government agencies, and thoughtful individuals.

The National Science Foundation's synthesis of these contributions to the *Five-Year Outlook* comprises the core of Volume I; the contributions themselves constitute Volume II. The individual contributions reflect the vigor and excitement of American science and technology, and illustrate the wide-ranging contributions that science and technology can make to the solution of problems faced by this Nation. While we all recognize that science and technology cannot provide a panacea for those problems, they do offer an impressive range of opportunities.

In this statement, which constitutes my personal overview of the *Five-Year Outlook,* I want to concentrate on six issues. These issues are discussed at greater length in the *Five-Year Outlook* and, in my judgment, warrant the special attention of the Executive and Legislative branches of the United States Government and of the American people:

1. Stimulating innovation and productivity in industry and agriculture.
2. Ensuring adequate supplies of energy and nonrenewable resources.
3. Improving the science and technology base for risk assessment.
4. Contributing to improvements in health.
5. Maintaining international leadership in science and technology.

The sixth issue undergirds these five:

6. Ensuring the continued vitality of the Nation's scientific and technological enterprise.

These issues will persist in some form well beyond the period of this *Five-Year Outlook*. All of them involve public choices that will have to be made within the next five years, and which deserve discussion throughout the Nation.

1. STIMULATING INNOVATIONS AND PRODUCTIVITY IN INDUSTRY AND AGRICULTURE

The declining rate of productivity growth in some industrial sectors is an important factor in the reduced economic progress of the United States. Productivity, in turn, depends in substantial measure on industrial innovations—the development and commercialization of new products and processes, and the improvement in the efficiencies of existing processes. As the recent Domestic Policy Review on Industrial Innovation clearly recognized, innovation is also an important factor in reducing inflation, assuring the availability of adequate supplies of energy, maintaining the Nation's international competitive position, and improving the quality of all of our lives.

The Domestic Policy Review announced new Federal initiatives in nine critical areas. Several of these initiatives provide opportunities for science and technology to spur industrial innovation and deserve continued attention during the next five years:

- Augmenting research on generic technologies that underlie several industries.
- Expanding cooperative programs of research between industry and universities.
- Increasing incentives to small businesses and large industries to undertake high-risk research.
- Refining the scientific basis of the regulatory system.
- Strengthening the patent system and clarifying anti-trust policy on collaboration in research and development.
- Helping labor and management adjust to technical change.
- Enhancing the dissemination of information to industry.

In agriculture, high productivity is essential to sustain domestic food supplies, to feed people in other countries, and to contribute to the Nation's balance of trade. Interest in using renewable resources for energy production and as substitutes for petroleum-based industrial chemicals is providing new challenges to American agriculture.

Factors that threaten agricultural productivity are rising costs of fuels and petroleum-based fertilizers, environmental restrictions on pesticide use, growing competition for water by new synthetic fuel industries (particularly in the semi-arid regions of the West), and effects of water and air pollution on crops. Since these factors will certainly persist into the next century, research should focus on the following long-range opportunities:

- Expanding fundamental knowledge of biological processes (such as photosynthesis, the relationship between photosynthesis and nitrogen fixation, carbon dioxide fixation, and the dynamics of cell membranes) needed to develop food plants that require less fertilizer and fresh water and are more resistant to inhospitable environments.
- Developing environmentally safe methods for controlling animal and plant pests and diseases.
- Augmenting knowledge of the effects of air pollution (particularly acid rain) on agricultural crops.
- Applying solar and biomass energy sources to reduce agriculture's dependence on fossil fuels.
- Using more effectively satellite data on atmospheric, oceanic, and land-surface dynamics to improve long-range agricultural management.

2. ENSURING ADEQUATE SUPPLIES OF ENERGY AND NONRENEWABLE RESOURCES

This Nation's industrial growth has been based on the ready availability of low-cost energy and other material resources. Worldwide shortages of petroleum will become increasingly severe during the remainder of the century. We need research to help achieve two urgent national goals: First, to reduce our dependence on foreign and diminishing domestic sources by conservation and substitution. Second, to develop environmentally safe alternative sources.

The ability of science and technology to help meet these goals will be influenced by policy decisions made during the next five years. For example:

- Additional petroleum sources need to be identified and evaluated. Research by government and industry to establish a scientific framework for the development of the ocean margins for that purpose should be intensified.
- The science and technology base for the synthetic fuel industry must be augmented quickly to assure that these fuels are available to provide a substantial part of the Nation's energy in the 1990s.
- We must improve the safety of conventional nu-

clear power plants, and pay greater attention to the role of human factors in the operation of the plants. We must also resolve radioactive waste disposal problems to retain for the Nation the option of nuclear fission as a source of energy.

- If advanced energy technologies (including nuclear fusion, photochemical fuels production from solar energy, and direct solar conversion) are to become the primary energy source during the 21st century, we must emphasize at once research that will provide the scientific knowledge for their development and commercialization.

- The ability to estimate uranium resources has been called into question by recent re-evaluations. It is important that geologists and geochemists develop improved techniques for estimating uranium deposits and a wide range of other mineral resources. Independent of estimated resources, we must begin immediately to design the next generation of reactors to be more uranium-efficient in order to extend the useful life of known deposits.

Petroleum is far more valuable as the basis for organic industrial products (including fertilizers, plastics and pharmaceuticals) than as a fuel. Rising petroleum prices will affect the costs and availability of these products. Foreign supplies of other organic raw materials essential to our economy, most notably rubber, could also be seriously disrupted. Thus, industrial use of domestic renewable resources should be pursued as a long-range option. Promising opportunities for the next five years include research on the feasibility of:

- Using domestic plants as sources of organic materials For example, guayule, a plant native to the arid lands of the Southwest, could provide an alternative to imported rubber, and jojoba, a plant that thrives in the same region, could become a source of lubricating oil.

- Extracting chemical feedstocks and petrochemical substitutes from coal and lignocellulosic materials (such as non-commercial species of trees, underutilized hardwoods, and lumber industry residues). The use of genetic techniques to produce microorganisms capable of converting these raw materials into useful chemicals is a particularly attractive possibility.

Expert opinions differ about the timing and impact on the American economy of world shortages of industrially important metals. Disruptions in the supply of some metals such as chromium have been experienced and are likely to recur with increasing frequency. Prices of others, such as copper, will rise as the richest and most accessible sources are depleted. National security considerations argue strongly against overdependence on a small number of politically unstable foreign sources for such primary resources. Promising opportunities related to the supply and use of essential metals that can be pursued during the next five years are:

- Using remote-sensing satellites and deep-probing radar to identify new mineral deposits and evaluate known deposits.

- Implementing technologies for improved extraction of metals from ores, sea water, and the ocean floor.

- Expanding research on the properties of materials, as a basis for substitution and new energy-efficient applications. For example, the replacement of metals and alloys with silicon ceramics in energy-conversion devices would permit higher operating temperatures and greater energy efficiencies.

- Pursuing research on the fundamental physical and chemical bases of corrosion, fracture and wear, thereby improving the durability and recycling potential of scarce materials.

3. IMPROVING THE SCIENCE AND TECHNOLOGY BASE FOR RISK ASSESSMENT

Science and technology often are critical in the identification of policy issues, in making decisions about environmental standards, and in assessing the risks of new technologies. If regulations are to become more rational, we must expand the science on which these regulations are based. Assessing a risk (whether to health, safety, or the environment) is a task combining both facts and values. The task is complicated by differing opinions of how much risk is acceptable for a particular level of benefit. It is usually possible to reduce the hazards associated with a given technology by spending enough money. It is also possible to eliminate the hazard completely by eliminating the technology. But the long-term social costs of foreclosing promising technological options by needlessly stringent environmental regulations are too easily overlooked.

More research is needed to understand the causal mechanisms underlying various risks and to implement appropriate control technologies. Ultimately society must determine the risks that individuals and groups should accept in exchange for the benefits of a given technology. But in the absence of better information about the effects of specific hazards, the governmental decision process cannot function effectively.

During the next five years there is an urgent need to determine the true range of effects of a large variety of hazards; to refine methods to detect and measure those effects; and to assess the economic and social impact of various risk-mitigation options. In particular:

- Many substances may pose risks to human beings and their descendants only at high levels of exposure. However, it may sometimes be prudent to assume, in the absence of evidence to the contrary, that any level of exposure presents some risk. Unfortunately, the costs of technologies to decrease the concentration of a contaminant in food or in the environment increase as the concentration decreases, often sharply so. Epidemiological studies provide the only direct means for assessing the effects of low-level exposure to chemicals and radiations; although these studies are expensive and involve evaluation over extended time periods, a balanced regulatory policy requires that they be actively pursued.

- Some toxic substances may produce adverse effects even in minute amounts. The development of analytical techniques for the rapid detection of such substances (permitting surveys to establish baselines and monitor changing levels) should be encouraged.

- Other substances may not be harmful except over long time periods or to future generations. Such effects can only be evaluated when underlying causal mechanisms are understood, and this requires fundamental research.

- Failure to recognize and take steps to mitigate hazards can entail serious risks; on the other hand, excessive conservatism in reducing such risks may entail social and economic costs that are not immediately obvious. An important priority is to improve analytical techniques to assess and compare the full range of costs, risks and benefits of specific regulations.

- If the political process is to operate effectively and fairly in setting acceptable levels of risk, then the public must be better informed about the complicated tradeoffs between risk mitigation and social benefit. High priority should be given to developing ways of facilitating knowledgeable public discussion about the regulatory process.

4. CONTRIBUTING TO IMPROVEMENTS IN HEALTH

Equitable access to high-quality health care for all Americans will receive considerable attention during the next five years. Many regard good health for everyone as an obtainable ideal, and this provides a striking example of the way science can change expectations. Scientific research has contributed to improvements in nutrition and sanitation, both of which are important determinants of health. Science has contributed to the control or elimination of many infectious diseases that were once widespread (such as smallpox, tuberculosis, pneumonia and polio).

As a result of these developments, the longevity of Americans has been augmented markedly during this century. But this has, in turn, magnified the seriousness of noninfectious diseases common to middle and old age, such as heart disease and cancer. These and other disorders (including arteriosclerosis, hypertension, and mental illness) are linked in part to environmental factors, and in part to lifestyle factors over which individuals have control.

Science and technology can contribute to better health by advancing our understanding of fundamental biological processes in health and disease; by expanding our knowledge of the effects of lifestyles on health; by enhancing the effectiveness of medical interventions; and by supporting improvements in public health and the delivery of health services. Specific opportunities include:

- Using recombinant DNA techniques to advance our understanding of genetics at the molecular level (thereby offering the possibility of detecting and correcting genetic diseases), and to produce essential pharmaceuticals, such as insulin and interferon, at lower costs and higher purities.

- Expanding our understanding of genetic and behavioral determinants of cardiovascular diseases, particularly hypertension and arteriosclerosis.

- Pursuing research on brain chemistry at the molecular level to increase our understanding of such problems as obesity, schizophrenia, depression, and mental retardation.

- Augmenting our knowledge of psychological and social determinants of alcohol and drug abuse, cigarette smoking, and other habits that adversely affect health and longevity.

- Increasing public understanding of the relationship between lifestyle, behavior and disease so that individuals will have a deeper appreciation of ways to maintain and improve their own health.

5. MAINTAINING INTERNATIONAL LEADERSHIP IN SCIENCE AND TECHNOLOGY

It is imperative that the Nation recognize the vital role that science and technology now play in international affairs. The international dimensions of energy, environment, food, and oceanic exploration are evident. Several industrialized nations have developed scientific capabilities that now approach our own. The lesser developed countries are seeking a larger share of the scientific and technological capabilities that are overwhelmingly concentrated in the industrialized countries.

The Nation's declining advantage in technology needs to be discussed widely and brought into focus. At the same time, the scientific credentials of other countries provide opportunities for bilateral and multilateral research projects. Examples of scientific activities from which the United States benefits by pooling its resources with other countries include:

- Participation in the Global Atmospheric Research Program which includes, among its objectives, better monitoring of the global climate and assessing climatic changes due to human activities (e.g., increased burning of fossil fuels).
- Collaborative research with Japan on nuclear fusion, photosynthesis, and synthetic fuel production.
- Collaboration with the People's Republic of China on earthquake prediction and earthquake damage mitigation.
- Cooperation with Mexico on research on the arid lands on both sides of the border, with emphasis on developing new crops and making effective use of scarce water resources.

Scientific cooperation with the lesser developed countries often requires a different approach than with industrialized countries—in part because our priorities for research may differ from theirs. Two examples illustrate the problems:

- The U.N. Law of the Sea Conference has yet to resolve issues relating to the control of ocean minerals or the question of free access to the oceans for scientific purposes.
- Demands by less developed countries for portions of the radio frequency spectrum for communications challenge the exclusive use of parts of the spectrum for research and other scientific purposes.

Opportunities to facilitate the transfer of science and technology to the less developed countries exist in several areas. In many cases such transfers can yield results of direct value to the United States. For example:

- Assisting less developed countries in planning for their future energy needs with due regard for conserving their own resources and minimizing adverse effects on the global environment.
- Developing more efficient ways to use agricultural wastes and nonfood crops as fuels and as substitutes for petroleum-based products.
- Improving technologies for locating and exploiting underground water resources and for desalting sea water.
- Pursuing collaborative research on the causes of desertification and deforestation and developing methods for returning land to productive uses.

6. ENSURING THE VITALITY OF THE NATION'S SCIENTIFIC AND TECHNOLOGICAL ENTERPRISE

Advances will be made in understanding and dealing with the problems identified in this *Five-Year Outlook*, in part because a firm scientific base has been established by past investments in research. But these problems will concern the Nation in some form for years to come. There is an understandable temptation to allocate resources to immediate and pressing problems at the expense of investments in longer term scientific and technological capabilities. However, if the Nation is to maintain its ability to face the future, it must deal with the problems that now confront its research institutions.

Specific needs and opportunities during the next five years are as follows:

- The recent Domestic Policy Review on Industrial Innovation stressed the desirability of cooperation between the public and private sectors to enhance the technical knowledge base in areas of interest to industry. Cooperative development of two classes of technologies deserves special emphasis: (1) generic technologies that underlie several industries, and (2) technologies required for compliance with environmental, health and safety regulations.

- Expanded university-industry cooperation will stimulate and enhance university research and make the results of research more accessible to industry. By providing opportunities for linkages among scientists and engineers in both sectors, cooperative projects will facilitate institutional arrangements whose significance transcends the value of any particular project.

- Problems created by the obsolescence of instrumentation and the increasing costs of new and more sophisticated scientific apparatus must be alleviated. These problems are particularly severe for university laboratories, but they also exist in industry. Regional instrumentation centers available to qualified scientists can provide a partial response to the problem, as well as greater attention to pooling equipment funds and sharing apparatus.

- The financial problems faced by universities cannot be resolved by the Federal Government. However, the government can help the universities remain viable research institutions by continuing to support high-quality research, and by reducing the costs of compliance with complicated Federal regulations, particularly those that do not take into account the special nature of universities.

- Decreasing university enrollments have caused a decline (as well as an age imbalance) in the faculties of many science departments. As a result, tenure positions for promising young scientists are, and will continue to be, scarce in several fields. This situation is likely to persist well into the 1990s. New opportunities must be found for young scientists to pursue careers in universities so that these institutions can continue to play a vital role in the Nation's science programs.

- Research opportunities in industry are increasing, and there is a growing need for scientists and engineers at all levels of government. Thus, messages about limited numbers of university faculty positions should not discourage young people from careers in science and technology. On the contrary, since the strength of the Nation depends strongly on the availability of highly motivated scientists, the flow of young people into science must be encouraged.

- More attention needs to be paid to technological innovations as an aid to instruction, and ways must be found to make teaching apparatus accessible to schools, colleges and universities. For example, computers can be used to tailor instruction to the needs of individual students, and provide students with on-line experience in problem solving.

SCIENCE AND TECHNOLOGY IN THE NATION'S FUTURE

The contributions of long-term research to the solution of national problems are illustrated by many examples in this *Five-Year Outlook*. But these examples focus on problem areas that have already been identified. In that respect they fail to convey the total contribution research makes to our society. In addition to research with clear applications, we need to strengthen the context in which scientific activities are pursued and to encourage research that has no identifiable applications. Polio vaccine, the laser, transistors, and integrated circuits were not realized because someone tried to solve a practical problem. Rather, they were the result of research carried out by well-trained and highly motivated scientists whose primary goal was a better understanding of nature. There can be no question that research underway now—with no identifiable applications—will in time lead to significant new developments.

Whether or not a particular research project has an identifiable application, the fact that it seeks an answer to a scientific question is a contribution in its own right. Splendid opportunities for advancing our understanding of problems that have long challenged the human intellect are described in this *Five-Year Outlook*. These opportunities, no less than those associated with specific societal problems, deserve attention and support.

This is the first *Five-Year Outlook* on science and technology prepared in response to the National Science and Technology Policy, Organization and Priorities Act of 1976. However, it is but one in a succession of government reports calling attention to the role of science and technology in dealing with national issues. One of the most important reports was written thirty-five years ago under the leadership of Vannevar Bush, the Director of the Office of Scientific Research and Development during World War II. The Bush report, entitled *Science—The Endless Frontier*, responded to a request by President Franklin D. Roosevelt to examine how the Federal Government and American science might cooperate in peacetime to "create a fuller and more fruitful employment and a fuller and more fruitful life." The report assessed the contributions that science and technology could make in the postwar years, and prepared a plan to marshal the Nation's resources to that end. Significantly, it focused on the need to make long-term public investments in scientific research.

The wisdom inherent in the Nation's acceptance of the Bush report's recommendations on long-term research is amply illustrated in this *Five-Year Outlook*. In this regard Dr. Bush's admonition deserves reemphasis.

> Science, by itself, provides no panacea for individual, social, and economic ills. It can be effective in the national welfare only as a member of a team. But without scientific progress no amount of achievement in other directions can insure our health, prosperity, and security as a nation in the modern world.

The Bush report was an assessment of national problems and a specific plan to mobilize science in the Nation's service. But it was more than that. Invoking a metaphor of the American West, it called on the Nation to join science in exploring the frontiers of the mind and spirit. The concerns and enthusiasms of American scientists and engineers reflected in this *Five-Year Outlook* convince me that the metaphor of an endless frontier is still very real. Finding more effective ways to use science and technology is among the most important challenges the Nation faces in the next five years.

Richard C. Atkinson

Introduction

CONTEXT OF THIS FIVE-YEAR OUTLOOK

With the passage of the National Science and Technology Policy, Organization, and Priorities Act of 1976 (Public Law 94-282), the United States Congress legislatively expressed its belief in "the profound impact of science and technology on society, and the interrelations of scientific, technological, economic, social, political and institutional factors."

As one means of developing a better understanding of the effects of science, technology and society on one another, the Act required that a *Five-Year Outlook* be prepared periodically to "identify and describe situations and conditions which warrant special attention within the next five years, involving—

"(1) current and emerging problems of national significance that are identified through scientific research, or in which scientific or technical considerations are of major significance; and

"(2) opportunities for, and constraints on, the use of new and existing scientific and technological capabilities which can make a significant contribution to the resolution of problems identified under paragraph (1) of this subsection or to the achievement of Federal program objectives or national goals, including those set forth in section 101(b) of this Act."

The goals set forth in Section 101(b) are generally concerned with advances—domestic and international, intellectual and material, personal and social—to which American science and technology can contribute.

Although this is the first *Five-Year Outlook* on science and technology to be prepared in response to this specific congressional directive, it is not the first time an agency of the United States Government has been asked to assess future opportunities and problems associated with the effects of science on issues of national concern. One notable precursor was *Science—The Endless Frontier*, written in 1945 by a task force headed by Dr. Vannevar Bush, Director of the Office of Scientific Research and Development during World War II, in response to a request from President Franklin D. Roosevelt for specific recommendations on how the scientific capabilities of the Nation could be used most effectively in peacetime to "create a fuller and more fruitful employment and a fuller and more fruitful life."[1]

The Bush report argued that since science had become essential to the national welfare, it had also become the proper concern of government. It recommended that the U.S. Government expand and improve its own research laboratories, encourage industrial research by changes in tax and patent laws, and offer fellowship opportunities to assure a steady supply of talented, well-trained scientists. Its most emphatic and, at the time, most original recommendation was that the Federal Government should provide strong support for the conduct of basic research in the universities as the most effective means of assuring an adequate knowledge base for the country to draw upon in resolving problems it would inevitably confront in the future.

A comparison of the changes that have occurred in the size and character of American science and technology from World War II until the late 1960s, and from the late 1960s through 1979, provide a useful context for this *Five-Year Outlook.*

The Bush report states that in 1940, the last full year before the United States entered the war, American universities awarded slightly more than 1,600 PhD's in the mathematical, physical and life sciences.[2] By 1965 the number of PhD's awarded in those fields in the United States had risen to approximately 6,000.[3] In that same year a total of 10,500 PhD's were awarded in all fields of the natural and social sciences and engineering. Three years later that number was well over 14,000. In 1965 slightly fewer than 500,000 full-time equivalent scientists and engineers were employed in research and development in the United States. Three years later their number was about 550,000.

In 1940, according to the Bush report, expenditures for scientific research by the U.S. Government, by industry and by the universities were $69 million, $240 million and $31 million, respectively, totalling $300 million.[4] In 1965 total research expenditures in the United States had risen to $6.89 billion and by 1968 to $8 44 billion, with the U.S Government's contribution being approximately twice that of the private sector. In 1965, total university expenditures for basic research were $1 14 billion, with the bulk of those funds derived from the Federal Government. By 1968 university basic research expenditures had risen to $1.65 billion, representing a 23 percent constant dollar increase over that three-year period.[5]

Clearly, the Bush report's general recommendations were at least consistent with, and were probably a principal stimulus of, the spectacular growth of the American scientific enterprise during the first two post-war decades. But that growth rate did not persist. The number of PhD's awarded in the mathematical, physical and life sciences rose to almost 10,000 in 1970, but by 1977 (the last year for which numbers are available) had declined to 8,600, which was roughly the 1968 level. Approximately 17,400 PhD's were awarded by American universities in all science and engineering fields in 1977, with the social sciences accounting for the major portion of the increase as compared with 1968. Total full-time equivalent numbers for all scientists and engineers working in R&D barely increased from about 550,000 in 1968 to about 570,000 in 1977. Their number was estimated to have risen to 610,000 by 1979.[6]

In 1977, total national research expenditures, in current dollars, were $15.32 billion, compared with $8.44 billion in 1968. However, constant dollar expenditures for these two years did not differ appreciably. Indeed, the 1977 level represents a recovery from a decline in constant dollar expenditures that began in 1969 and continued through 1975. Total national constant dollar expenditures for research and development and for basic research conducted in the universities also declined markedly during the early 1970s. However, by 1977 both had again risen to approximately their 1968 levels.

The situation has continued to improve. In 1979, total national expenditures for all research and for research and development (measured in constant dollars) were about eight percent above 1977 levels. By 1979, private industry's contribution to total national research expenditures was almost two-thirds that of the U.S. Government, while industry's research and development expenditures approached equality with the government's. Constant dollar expenditures for all basic research increased by more than 14 percent, and for basic research conducted by universities they increased by almost 16 percent. These latter increases reflect explicit decisions by the Carter Administration to make basic research a high priority item in each of its budgets.[7]

The leveling off of national expenditures for research and development which began in the late 1960s and persisted throughout most of the 1970s can be attributed largely to economic and demographic factors. The decline of Federal investments in research during the latter years of the war in Vietnam was particularly striking. It is also worth observing that the sharply different growth trends from World War II to the late 1960s and from the late 1960s to the present are paralleled by changes in the national mood. The Bush report was written during the final months of a war that seemed, to many, to establish both undisputed world leadership for the United States and a new unity of purpose among its citizens. Science and technology had been central to what President Roosevelt called the "vision, boldness, and drive" with which the war had been waged.[8] The "endless frontier" metaphor seemed entirely appropriate in 1945, for there appeared to be virtually no limit to what science and technology could accomplish for the United States, or what the United States could accomplish both for itself and for the world.

By the mid-1960s that sense of national unity and purpose had been dampened. Serious doubts were being expressed about the tacit assumption that economic growth was in and of itself an undisputed good. Science and technology, as major contributors to growth, were being implicated in some quarters as major contributors to the adverse *effects* of growth. The war in Vietnam placed heavy pressures on the controllable parts of the Federal budget. And scientists and engineers themselves were beginning to see more clearly the wisdom inherent in the Bush report's warning that "Science, by itself, provides no panacea for individual, social and economic ills."[9]

President Carter's budget requests and his March 27, 1979, science and technology message to the Congress have demonstrated his strong commitment to scientific research. Recent annual increases in total Federal support for research and for basic research conducted by universities, measured in current dollars, have been at least as high as they were during the early 1960s. Unfortunately, continuing high inflation rates have resulted in a diminution of increases in constant dollar terms. However, the opportunities to advance knowledge and understanding over a wide range of scientific disciplines are in no way diminished. The metaphor of the endless frontier of the mind and spirit persists for most of those directly engaged in scientific research. Among scientists and engineers, only a few here and there perceive internal limits to the potential achievements and benefits of science and technology.

The non-scientist public, for its part, seems to have adopted an attitude of watchful expectation toward science and technology. Opinion polls indicate that a clear majority of Americans remain supportive.[10] But probably few believe, if they ever did, that science and technology offer unique or easy solutions to problems of individual and social concern. Many are prepared to believe that science and technology still hold great promise for the Nation. But many also want to know exactly how science and technology can be brought to bear on problems of national interest, and what the economic and social costs and benefits of various feasible options will be.

The Carter Administration's strong commitment to research offers considerable hope that the period of increasing investments will continue into the 1980s. Hence, the present is an especially opportune time to assess the potential of American science and technology to provide insights and tools to contribute to the diagnosis and solution of the many problems the Nation will face during the first half of the 1980s.

HOW PREDICTABLE ARE SCIENCE AND TECHNOLOGY?

Several questions arise in any attempt to assess future problems and opportunities for science and technology and their future impacts on national policy concerns. Perhaps the most difficult of these has to do with the different time scales of science (particularly basic research), technology and the legislative process.

Basic research is a quest for new knowledge about questions that have been posed in a general way since antiquity: What is the nature of matter and of the universe? What is the nature of life? What is the nature of human society? Data are acquired, and cause-and-effect relationships are sought among those data. Occasionally, recognition of a certain causal pattern leads to a profound new insight which points an entire discipline in a new direction (or even establishes a new discipline) and necessitates a new program of data collection and the search for new patterns. It is not too difficult to predict the *minimum* level of progress that a field of basic research will achieve in five years, at a particular level of support: one simply assumes that data will be acquired at a rate limited only by resources. *But there is no way to predict if, when, or whether a fruitful new pattern may be recognized to upset the conservative predictions.* By the same token it is almost impossible to predict anything about a particular subfield of basic research twenty years from now. For unless a line of inquiry yields useful insights within that time limit, the inquiry will probably be altered significantly, and may even be abandoned as fruitless.

Technology focuses upon the solution of more specific, practical problems by drawing, in large part, on existing knowledge and theory. For that reason its future course can be assessed with greater confidence. If adequate support and a sufficient scientific base exists, time periods on the order of a decade are required to initiate and carry a development to completion. Thus most technological innovations that are likely to be available in five years are already, today, in an advanced stage of development. Major new insights derived from basic and even applied research are unlikely to accelerate such developments, though they may suggest more effective ways to proceed in the future. Twenty-year predictions for developments requiring a decade to complete are more difficult to make, since new research results can make a significant difference if they are incorporated at the initial planning stage. Such predictions are somewhat more reliable for developments that approach or exceed a twenty-year time scale, though even in these cases new research results can alter both the course and prospects of those developments.

How, then, can statements that are useful to policymakers and that have significance over a five-year time scale be made about opportunities and problems for science and technology? One answer assumes that, barring a severe national emergency (such as war or a major depression), most of the important social and economic effects of science and technology that will be apparent in five years will be the result of discoveries already made and developments already well underway. Decisions about priorities for science and technology made during the next five years, however, can and will have measurable effects in the period *beyond* the next five years. Thus, a five-year outlook can describe laboratory and technological developments now underway whose effects are likely to be apparent in five years. It can point to areas of scientific research that are likely to yield sufficient results in five years to permit us to define the prospects for particular lines of technological innovation. Finally, a five-year outlook can speculate about possibilities that could exist in the more distant future, given the persistence of present trends, suggest the types of policy decisions and preparations that would have to be made during the next five years to realize or change those possibilities, and explore the broad social consequences that might follow if those long range possibilities were realized.

All three types of statements appear in this *Five-Year Outlook*.

PLAN AND PREPARATION OF THE FIVE-YEAR OUTLOOK

When the National Science Foundation initiated the design of this, the first *Five-Year Outlook* prepared in response to the Science and Technology Policy, Organization and Priorities Act of 1976, it was aware that no real models or prototypes existed for the type of report defined by the Act. Consequently, the Director of the National Science Foundation, in consultation with the Office of Science and Technology Policy, decided that this *Five-Year Outlook* should be regarded as an experimental, pilot project that would be useful in its own right, and could also provide guidance for the preparation of subsequent *Five-Year Outlooks*.

It was further decided that the *Five-Year Outlook* would be prepared in two steps, and that decision is reflected in its structure. In the first step, self-contained contributions were invited from several different sources. These contributions sample the views of scientists, engineers, administrators, and policy researchers about problems and opportunities in science and technology and about the probable impact of science and technology on issues of policy interest. In the second step, opportunities, problems and policy questions that appear to warrant special consideration during the next five years were extracted from these sources and synthesized under eight topical headings.

Thus, the source materials which make up Volume II are divided into three sections: (1) a report prepared by the National Academy of Sciences (NAS) which focuses on current and emerging problems and opportunities in selected areas of science and technology; (2) reports prepared by 21 U.S. Government agencies that discuss opportunities and problems in the relationships of science, technology and public policy from the perspectives of the individual agency missions; and (3) papers commissioned from individual specialists which provide their views and assessments concerning the relationships between science and technology, public policy and practice and selected socioeconomic goals. The views expressed by the National Academy of Sciences' report and by the specialists who contributed policy-oriented papers to Volume II are their own and do not necessarily reflect the views of the Director of the National Science Foundation or the United States Government. However these contributions, together with the U.S. Government agency reports, do provide a broad, if necessarily incomplete, range of perspectives on problems and opportunities in the relationships of science, technology and other areas of public concern.

The contents of Volume I were written entirely by the National Science Foundation, which bears sole responsibility for them. The topical syntheses that follow this Introduction are based, in part, on a preliminary analysis of the source materials by Dr. John Pierce, Professor of Electrical Engineering, California Institute of Technology. They highlight the source materials by identifying and describing the most significant opportunities and problems in several broad areas—for example, energy, materials, agriculture, and health—in which science, technology and public policy and practice are interrelated. Although the source materials include reports from services and agencies of the Department of Defense, subjects strictly taken from defense science and technology are not discussed in the summary sections that follow. Such discussions would require access to materials that are unavailable to the general public for reasons of national security.

Volume I also includes a synopsis of the agency reports and commissioned papers, which was prepared by, and is the responsibility of, the National Science Foundation. This synopsis is intended to serve as a guide to these materials. The views expressed in the synopsis of the commissioned papers, like the papers themselves, are not necessarily those of the Director of the National Science Foundation or the United States Government. Acknowledgements and an analytical index to both volumes complete Volume I.

Each of the contributions to the source materials that appear in Volume II was reviewed and in most instances revised before the final manuscript was assembled. In addition, the complete draft manuscript of both volumes was evaluated late in October 1979 by reviewers representing the perspectives of state and local government, academia, industry, professional scientific and engineering societies, law, medicine and the broader public interest. Many of the comments and suggestions made by reviewers have been incorporated into this *Five-Year Outlook*. Others will shape the design of the next *Five-Year Outlook*.

The methods that were used to prepare and evaluate the materials of Volume II varied, depending on their nature and source. The report of the National Academy of Sciences (NAS) was prepared by a steering committee chaired by Dr. Ralph E. Gomory of the International Business Machines Corporation and composed of those who were principally responsible for the preparation of the chapters. NAS established a two-tier review procedure: a review of initial drafts by members of the NAS, the Institute of Medicine, the National Academy of Engineering, and units of the National Research Council; and a final review, before release of the report to the National Science Foundation, by the Governing Board of the National Research Council. The final report was transmitted to the National Science Foundation on March 30, 1979. A commercially published edition is available from W.H. Freeman and Company, San Francisco.

Contributions to the *Five-Year Outlook* were requested from all U.S. Government departments, agencies and bureaus whose estimated obligations for research and development for fiscal year 1978 exceeded $100 million. The Department of Housing and Urban Development, the Department of State, and the Food and Drug Administration were also invited to submit reports. Collectively, these 21 departments, agencies and bureaus are responsible for 97 percent of the total Federal obligations for research and development. In requesting contributions to the *Five-Year Outlook* from the heads of these organizations, the Director of the National Science Foundation emphasized the importance of addressing their respective concerns in the context of the National Science and Technology Policy, Organization and Priorities Act of 1976. Individual reports were evaluated and cleared according to the internal procedures of the respective organizations, and with the cooperation of appropriate examiners of the Office of Management and Budget, before release to the National Science Foundation in late August 1979. The full set of reports was then edited to achieve a consistent format.

Topics and authors for the individual commissioned papers were determined by the National Science Foundation staff following consultations with individuals from a broad range of organizations, including academic institutions, private industry, labor, public interest groups, and from several U.S. Government agencies, including the Office of Science and Technology Policy. Drafts were sent to technical experts for review. Most of the drafts were revised by their authors to incorporate the significant comments of those reviewers. The last of the revised papers was delivered to the National Science Foundation by mid-September 1979, after which the full set was edited to achieve a consistent format.

Shortcomings were expected, and some of those that are now apparent should be mentioned. Given the scope of all science and technology in the United States, as well as the size of the family of disciplines that comprise science and technology, it could not be expected that the report would cover all important fields or all significant national policy concerns related to them. The topical syntheses of Volume I are based on the materials in Volume II and of necessity reflect their selective approach. The selections made by the National Academy of Sciences' report were not intended to reflect relative merits or priorities and many significant areas, such as mathematics, chemistry and many of the social sciences, were deferred for inclusion in future reports. The set of commissioned papers is intended to illustrate several types of interactions among science, technology and current national concerns rather than to represent the entire range of significant policy issues associated with science and technology. They were written by individuals who were asked to provide their expert views rather than the consensus of an entire scholarly field. In some cases more than one paper on a particular issue was commissioned in order to present alternative views or assessments. Discussions of several additional policy issues, including the status of basic research in industry, the comparative performance of U.S. technology, commercialization of science and technology, risk assessment, and science literacy, appear in the first and second *Annual Science and Technology Reports*, which were also prepared in response to Public Law 94-282.

Since contributions to the source materials were prepared by different individuals or organizations, they inevitably reflect the expertise and perspectives of their authors. And because most of these contributions review current and immediate problems and opportunities rather than attempt to provide original insights, much of the information in Volume II can be found in other published sources. Thus, this *Five-Year Outlook's* primary claim to originality must rest upon the assembly, organization and interpretation of the information and insights derived from diverse sources. It presents a collage of problems and opportunities over a broad range of science, technology and policy rather than a set of individual in-depth studies.

A good deal of the material in this *Five-Year Outlook* is concerned with the relationships of science and technology with other sectors of society. Therefore, developments in areas outside of science and technology (international upheavals, the state of the national economy, or particular legislative initiatives) will limit the reliability of conjectures about the future. In many cases trends in these areas may be even more difficult to predict than are trends in science and technology.

Finally, no attempts have been made to provide quantitative predictions of likely developments of policy interest, although available assessments based in part on such prediction (in the summary discussion of energy supplies, for example) are referred to when they are regarded as reliable. Quantitative techniques do exist for making forecasts about econometric and demographic aspects of issues of national concern. But the methodology for carrying out quantitative forecasting of other aspects of these issues is not available.

Despite these limitations, the National Science Foundation believes that this *Five-Year Outlook* provides a useful sample of the range of current problems and opportunities associated with the mutual relationships of science, technology and society. It remains to be seen whether it will also serve the stated objective of setting a useful precedent for the design and production of future *Five-Year Outlooks*. The attainment of that objective will require, at a minimum, that users and potential users make their comments, suggestions and criticisms known to the National Science Foundation.

NOTES

1. Roosevelt, Franklin D., Letter to Vannevar Bush dated November 17, 1944, reproduced in Bush, V., *Science—The Endless Frontier*, issued July 5, 1945, reprinted July 1960. Washington, D.C.: National Science Foundation, pp. 3-4.

2. Bush, op. cit., pp. 177-178. Reliable information on the numbers of PhD's awarded in the social sciences and engineering or about numbers of scientists and engineers employed in R&D activities prior to 1954 is not available.

3. National Science Board, *Science Indicators 1978*, Washington, D.C.: U.S. Government Printing Office (1979), Tables 5-4 and 5-23.

4. Bush, op. cit., pp. 85-89. Since the methods used for determining research expenditures in 1940 are not specified in detail in this reference, care should be taken in making direct quantitative comparisons with post-1960 data.

5. National Science Board, op. cit., Tables 2.3, 2.7 and 2.12. The preliminary 1977 numbers and estimated 1979 numbers that appear in these tables have been replaced by more recent data compiled by the National Science Foundation's Division of Science Resources Studies.

6. Ibid.

7. Ibid.

8. Bush, op. cit., p. 4.

9. Bush, op. cit., p. 11.

10. National Science Board, *Science Indicators 1976*, Washington, DC: U.S. Government Printing Office (1977), pp. 168-182; National Commission for the Protection of Human Subjects, *Special Study. Implications of Advances in Biomedical and Behavioral Research*, U.S. Department of Health, Education, and Welfare, DHEW Publication No. (OS) 78-0015 (1978), pp. 25-35.

The Outlook: Topical Syntheses

The source materials that comprise the second volume of this *Five-Year Outlook* identify many contributions that science and technology can make to illuminate and resolve problems of national concern. Some of these opportunities and problems are unique to a particular field of effort or to a specific type of institution. Others emerge, with some variation, from several contributions, suggesting that they have broader significance.

This section summarizes the most important information in the source materials under eight topical headings, and is intended as a guide to the source materials. The eight topics do not exhaust the discussions in the source materials of the probable directions for science or for technology or the issues that they raise for public policy considerations. The topical syntheses do, however, cover most of the areas of agreement among contributors on problems, opportunities, and near-term trends.

The topical headings are:

1. Energy
2. Materials
3. Transportation
4. Space
5. Agriculture
6. Health
7. The Electronic Revolution
8. The Perception and Management of Hazards and Risks

Abbreviations in parentheses refer to source materials. Chapters from the National Academy of Sciences report are referenced as "NAS," followed by the chapter number; U.S. Government agency reports are referenced by the abbreviated agency name, as given in parentheses in the Table of Contents; and commissioned papers are referenced by the name of the author.

1. ENERGY*

Some Problems Are:

- How to improve the availability of adequate and safe energy supplies for the Nation's needs, for now and in the long-range future.
- How to conserve limited energy supplies with minimal disruption of our society.
- How to improve public understanding of hazards and benefits associated with energy supply and use.

Some of the Opportunities for Using Science and Technology Are:

- To reduce energy use and reliance on uncertain energy sources wherever possible by conservation and by material and functional substitution.

* This section draws upon the Department of Energy's *National Energy Plan II*, released in May 1979, in addition to other sources. References to this source are designated "NEP II."

- To improve the use of both coal and uranium as energy sources.
- To explore and develop new domestic sources of fossil fuels.
- To improve extraction efficiencies of fossil fuels from existing sources.
- To pursue research and development aimed at (a) the greater use of renewable resources; and (b) the eventual primary use of solar and advanced nuclear energy sources.

OVERVIEW

The United States requires vast amounts of energy to maintain the high quality of life of its citizens. Most of that energy now comes from nonrenewable fuel sources: petroleum, natural gas, coal, and uranium from rich ores. Three-quarters comes from oil and natural gas which are being used at ever-growing rates while world supplies are being depleted. Most transportation and most space and industrial heating and cooling also depend on these two sources. Coal and uranium presently provide 22 percent of the Nation's energy and are used primarily to generate electricity (NAS 5, DOE, NEP II).

Unless the United States reduces dependence on imported fuels, continuing trade deficits and dislocations in its economy can be expected. Studies of trends and of available technologies and resources indicate that this challenge can be met only by conserving energy and shifting toward a greater reliance on coal and, ultimately, on renewable and advanced nuclear energy sources (NAS 5, DOE).

Efforts to conserve energy and to shift toward alternative energy sources depend heavily on science and technology and also involve policy decisions that require support from an educated public. To a major extent, they must also take place in sequential steps. Some of the important steps cannot be started during the next five years. Indeed, they cannot take place at all unless earlier steps have been successfully completed (NEP II). Therefore, the Nation's long-range energy future will depend critically upon decisions made during the next five years to implement these earlier steps.

The Department of Energy's national energy strategy conveniently groups these steps into three sequential phases. The first or near-term phase extends over the next five years. The second or mid-term phase extends from 1985 to 2000. The long-term phase begins with the year 2000 and extends into the indefinite future (NEP II).

During the near-term phase, the next five years, two kinds of activity will be emphasized. First, conservation and energy resource development will be continued. Second, scientific research and development to lay foundations for the mid-term and the long-term phases will be pursued.

Petroleum and natural gas are expected to remain as important components of the Nation's energy base until the end of the century. However, the mid-term phase should be characterized by a decreasing dependence on these fuels and a corresponding increasing reliance upon coal, liquid and gaseous coal derivatives and conventional, light water nuclear reactors. Solar and geothermal sources are expected to make a relatively small but increasingly important contribution during this phase (NAS 5, DOE, NEP II).

Coal and uranium can remain as significant energy sources well into the long-term phase provided a number of formidable technological and environmental problems are solved. Energy strategies for the long-term future also envision heavy reliance on solar energy and, hopefully, nuclear fusion energy. A great deal of research and development must precede the implementation of technologies to supply long-term U.S. energy needs. But since they use resources that are plentiful, renewable or inexhaustible, their promise must be pursued (NEP II, NAS 5).

Impending changes in the types of sources that constitute the Nation's energy base, even if the changes are years away, will require some changes in styles of living and working. Sharply rising gasoline prices have already altered driving habits somewhat, and near-term measures designed to conserve fuels will alter other habits. More fundamental changes are likely to occur, starting in the near term. For example, coal, nuclear fission and fusion, and a good many proposed geothermal and solar systems yield electricity as their directly usable product. Liquid or gaseous fuels can be extracted from coal, oil shale, and some agricultural products. However, the costs of liquid fuels are likely to be high relative to present costs of petroleum products and natural gas. For these reasons, a long-term shift to a more electrically oriented society is a real, though uncertain and controversial, possibility. This shift may require policy choices on such matters as public support for the development and commercialization of off-peak storage sytems; substantially electrified, mass ground transport; and increased use of heat pumps for heating and cooling buildings (NAS 5).

CONSERVATION AND ENERGY RESOURCE DEVELOPMENT

Conservation is the more immediate of the near-term priorities. Two strategies are being pursued, both of which require some adjustment in industrial practice and public use. In the near term, in fact immediately, Americans can simply use less energy. Regulations such as those regarding temperatures in public buildings and the

55 mph highway speed limit will serve this aim, as will reduction in the use of private automobiles. The second conservation strategy will be primarily carried out in the mid term; it requires more substantial changes in the economic structure of daily living: for example, new, less energy-intensive manufacturing and agricultural practices, and changes in housing and transportation design. Passive solar heating can save oil and natural gas, and it is in this way that solar energy is likely to make one of its most important mid-term contributions. These changes are intended to conserve energy by using it more efficiently. To have appreciable effects in the mid term they must be planned during the next five years, largely on the basis of scientific knowledge that is already available (NAS 5, 6; USDC; DOE; DOT).

It has been speculated that communications might save energy by reducing transportation needs, although the evidence on this point is still uncertain. Instead of having to travel to a bank to make financial transactions, people can make more use of the telephone and electronic funds transfer systems. Communication by means of electronic mail and conferences by means of computers are now feasible and will probably be used more during the next five years. What is uncertain is whether this will actually substitute for transportation or whether it will merely facilitate decentralization, which may accelerate transportation demands (NAS 4, 6).

Energy can also be conserved by using available materials technology. For example, a recent technological development, directional solidification of molten nickel-based superalloys, endows them with high-temperature strength. Controlled solidification can produce single-crystal turbine blades, use of which promises to extend the performance, life, and efficiency of gas turbine engines (NAS 6).

Other savings through materials science are feasible, and some seem likely to be realized in the mid-term phase: fluorescent lights with improved efficiency and color may find greater use for better home lighting; industrial plants may heat themselves with process heat; superconductors may improve the efficiency of generators and motors; ceramics may be employed in turbines and heat exchangers for greater energy efficiency; lighter metals may be used more extensively in cars for improved gas mileage; and such new energy-conserving technologies as the chloride cell for refining aluminum may be used (NAS 6, NSF).

Additional progress should also be made toward recycling materials Recycling aluminum saves 95 percent of the energy needed to make new metal from bauxite. Recycling manufactured products as opposed to recovering the materials they contain also offers significant potential for recovering the energy invested in their manufacture It would yield the additional benefit of reducing the solid waste resulting from manufactured products. In addition, a change from mechanical to electronic technologies in many applications may increase the durability of products and thus decrease materials needs for manufacture and replacements (NAS 6).

During the next five years the United States should lay the foundations for both its mid-term and long-term energy future. The mid-term future will rely on technologies that are now being developed or for which a scientific basis already exists (NAS 5, NEP II). Throughout the mid term the energy choices will be mainly limited to existing fuels. Therefore it is crucial that new, reliable, nonrenewable resources be located and known sources evaluated. Satellites can help locate oil fields and sources of geothermal energy during the next five years. Such techniques as multichannel seismic reflection and the use of submersibles and drill ships can be improved to help find petroleum and gas in the sea bed (NAS 5, DOE, GS, NASA). Technologies must also be refined for more efficient extraction of oil and natural gas from existing sources, including sources that have been abandoned (NEP II).

COAL

During the mid term, the United States will have to begin to shift from reliance on oil and gas to forms of energy which are more costly to convert to utilizable forms, primarily coal and nuclear fission. Because coal and nuclear energy offer both opportunities and major unsolved technological problems, the Nation must prepare to use *both* sources, while we decrease reliance on oil and natural gas. In the near term, attempts will be made to solve scientific and technological problems affecting the use of both sources (NEP II).

Coal is the Nation's most abundant fossil fuel; even the most conservative estimate forecasts enough for at least a century so that, were the size of the reserve the only obstacle, coal could be relied on as a bridge into the long term. All mid-term energy options place heavy reliance on the use of domestic coal supplies. Coal can be used to supply electricity by direct combustion. Along with oil shale, it seems to be the best source for making synthetic gaseous and liquid fuels (NAS 5, DOE).

The following costs associated with the Nation's increasing reliance on coal will have to be studied in the next five years. New facilities, some quite large, will have to be constructed for mining, transporting and burning coal and for extracting synthetic fuels from coal and oil shale. Combustion produces pollutants, and contributes to a global increase in atmospheric carbon dioxide. Large-scale use of coal involves increased strip mining with its attendant environmental problems and increased use of water resources. Assessments of the long-term environmental effects of these problems will require near-term research to gain more knowledge of global climatic conditions and changes in those conditions, and to assess the Nation's available groundwater resources (NAS 5, DOE, EPA, GS).

The increased cumulative buildup of atmospheric carbon dioxide and its effects on global climatic conditions will ultimately limit the use of coal and coal derivatives as energy sources. Advanced technologies that yield more usable energy for a given amount of coal may well be feasible and should be regarded as important options. However, considerable economic and environmental damage could result from placing too heavy a reliance on coal in the absence of technologies that can deal with the problems its use entails (NEP II).

NUCLEAR FISSION

Since coal probably cannot supply all of the Nation's mid-term energy needs without causing severe problems, nuclear fission must remain an important option. Otherwise the Nation will not be able to effect a sufficient reduction in imported petroleum. A balanced energy strategy requires that nuclear fission should provide one-fifth of the Nation's energy supply by 1985. At present, and during most of the rest of the century, light water reactors which use enriched uranium fuels will account for almost all of the energy derived from nuclear fission. During the next five years efforts will be continued to resolve reactor safety and radioactive waste disposal problems, both of which presently threaten to restrict the nuclear fission option (NAS 5, DOE, NRC).

Conventional light water reactors use nuclear fuels inefficiently and will eventually deplete most known available sources of rich ores. Thus, if nuclear fission is to help meet the Nation's long-term energy needs, progress must be made toward the development of advanced reactor technologies in the near-term future. Breeder reactors would produce plutonium-239, itself a nuclear fuel, at the same time that they generate electricity. Thus, the use of breeder reactors would yield up to 70 times the amount of energy from a given amount of uranium than is possible from light water reactors, and uranium could therefore become a plentiful rather than a scarce fuel. However, for full advantage one needs to reprocess and recycle spent fuel elements to recover the plutonium-239 that is manufactured. The recovery processes would raise problems associated with the fact that the plutonium-239 recovered by current reprocessing technologies can be used to produce nuclear weapons. For this reason the Administration has deferred a decision about whether to proceed with a demonstration of the feasibility of breeder reactors until an interagency review and an International Nuclear Fuel Cycle Evaluation are completed. However, research and development on the science and technology of breeder reactors, if carried out in the next five years, would allow commercial development consistent with non-proliferation policies (NAS 5, NEP II).

A possible alternative to the breeder reactor may be the development of advanced converter reactors. Canada's CANDU heavy water reactor, if redesigned to accept slightly enriched uranium in a once-through cycle, would be an example. By comparison with its light water counterpart, such a reactor would use only about half as much uranium to generate the same amount of energy with little or no fuel reprocessing (NAS 5).

Development of a national nuclear energy program will depend at least as significantly on a political and public consensus as it will on scientific and technological advances. The Three Mile Island accident and public uncertainties about risks associated with nuclear fission as an energy source have emphasized this principle once again. More generally, implementation of any energy strategy depends on decisions by an educated public. The American public needs scientific and technological information to better understand not only the costs, risks, and benefits associated with individual energy options, but also the long-range economic and social costs of foreclosing any option. Thus, present efforts to improve public understanding of technical issues must be continued and intensified in the near term (NAS 5, NRC, Nelkin).

GEOTHERMAL AND SOLAR SOURCES

Geothermal technologies make use of the natural heat stored in the earth and use the following main sources: hydrothermal sources, such as geysers; geopressured sources containing dissolved natural gas; and hot dry rock. They are expected to provide some of the energy needs of some regions of the country, by the end of the mid term. But, in order to get substantial energy from these technologies, research must develop new techniques for locating geothermal resources, for direct heat applications of geothermal fluids, and for development of new drilling technology (DOE, NEP II).

Solar energy reaches the earth in the form of visible and invisible radiation, and manifests itself in several ways: as light and heat; in the growth of plants that thus act as solar energy storage systems; and as one important governor of the circulation of the earth's atmosphere and its ocean currents. The problem of using solar energy, in all cases, is to find economically competitive ways to convert the energy into usable forms.

"Passive" solar hot water and space heating systems are already in use, and will surely be used even more because rising costs of heating oil and gas will make them economically competitive. Commercialization of other conversion technologies must be preceded by considerable research and development. Several types of systems show promise of more widespread use before the end of the century: active solar space heating systems, wind energy conversion systems, and systems for conversion from biomass to liquid fuel. The burning of non-commercial woods and agricultural waste products at or near the place they are produced (perhaps on farms) yields energy while avoiding most transportation costs. Making alcohol from agricultural wastes and adding it to gasoline to make gasohol is technically feasible; the economic feasibility of the process should become clearer within the next five years (NAS 5, NSF, DOE, NEP II).

Costs associated with the widespread use of solar energy need to be assessed in more detail. Extensive biomass conversion might divert considerable agricultural land from food production. Moreover, all solar energy conversion systems require a considerable investment of nonrenewable and energy-intensive mineral resources which partly offset the abundance and cheapness of the energy source itself. One of the principal objectives of solar energy research is to find ways of reducing these ancillary resource requirements. To the extent that this goal is achieved, solar energy is increasingly likely to become a primary option for the Nation's long-term future (NAS 5, NEP II).

NUCLEAR FUSION

Nuclear fusion, the process through which the sun converts its mass into energy, might also provide an important option for the long-term future. Most designs that are regarded as feasible would use lithium, a relatively abundant element, as a fuel. Exceedingly high temperatures need to be attained before fusion reactions can be initiated. In the process, the atoms of the fuel lose several electrons and the fuel itself becomes a plasma; that is, a hot, charged, ionized gas. Scientific knowledge about the properties of plasmas is far from adequate. The technical problems involved in raising plasmas to sufficiently high temperatures for fusion to occur and confining them to small volumes at those temperatures are formidable and have yet to be resolved. During the next five years, research on the properties of plasmas and engineering studies aimed at solving major technical problems will be pursued with the objective of demonstrating the engineering feasibility of fusion as an energy source sometime during the mid-term future. Even if these demonstrations are successful, the first commercial use of fusion will not occur until the 21st century. Since the ultimate promise of fusion as an energy source is large and the problems of successful implementation are formidable, international cooperation with several countries in fusion research and development has been initiated and is expected to substantially reduce the costs of these activities to the United States (DOE, NEP II).

2. MATERIALS

Some Problems Are:

- How to improve the continued availability of essential nonfuel materials for the Nation's needs.
- How to encourage urgently needed conservation of, and substitution for, scarce materials, or those particularly susceptible to supply interruptions for political reasons.
- How to improve capabilities to develop new classes of materials that will be needed for future innovations.

Some of the Opportunities for Using Science and Technology Are:

- To improve the extraction of raw materials from existing deposits.
- To improve technologies for recycling materials.
- To find new deposits of raw materials and evaluate existing deposits, using remote-sensing and other methods.
- To develop metals, ceramics and polymers with improved characteristics.
- To test domestic plant species as renewable sources of substitutes for petroleum-based chemicals and other scarce organic substances.

OVERVIEW

Industrial activities in the United States depend on a continuous supply of nonfuel materials. These include both common metals and alloys and a number of highly specialized materials. These specialized materials have been—and are being—developed in response to a range of needs. Examples of developments that show considerable future promise include: low-cost solar cells for converting sunlight directly to electricity; more efficient lighting with improved color; environmentally safe replacements for polychlorinated biphenyls (PCBs); new infrared detector materials capable of locating objects by their heat emissions; dielectric materials for high-density energy storage; fiber optics with improved message capacity; high-performance metal, polymer, ceramic, and composite replacements for missing or defective limbs, joints, or other parts of the body; low-cost silicon chips for use in increasingly complex integrated circuits; and new magnetic materials for use in computer memories (NAS 4, 5, 6; DOE; NIH).

However, several factors threaten to limit the ability of the Nation's materials industry to meet the rising demand for its products, including new, specialized products and traditional ones as well. These factors include: a growing dependence on foreign sources of raw materials; increasing competition from other countries for world supplies; higher costs of transport; uncertainties about innovation in the domestic, nonfuel minerals industry; adverse environmental, occupational safety, and health effects associated with producing, using, and disposing of minerals and materials; and higher costs and possible shortages of energy. The materials industries tend to be energy intensive, and the declining quality of resources, the need for pollution controls, and the adoption of many of the new technologies often increase energy requirements (NAS 6, USDC, BM, State) in a changing world whose national rivalries and aspirations increasingly influence access to materials (State).

Science and technology are making contributions in several categories to ensure that the Nation's material needs are fulfilled: exploration and extraction, conservation (including substitution) and processing, and materials research and development.

EXPLORATION AND EXTRACTION

The most promising exploration and extraction strategies for improvement over the next few years include: environmentally acceptable mining of the remaining shallow, large-volume deposits capable of producing yields of more than one substance; exploration and extraction of higher grade deposits at greater depths; development of improved geophysical and geochemical exploration techniques, including satellite remote sensing and deep drilling; and exploitation of potentially vast marine mineral resources (NAS 1, 6; USDC; BM; GS; NSF; NASA; State).

Information about natural resources will come from applications of new scientific knowledge about the earth. The theory of plate tectonics ranks among the great unifying ideas in science, since it provides a conceptual framework for understanding and linking together a wide range of diverse processes that occur on the earth. A better understanding of these processes will continue to be sought, in part because they touch upon many issues that are likely to remain important during the next five years, including the location of mineral deposits (NAS 1).

Prospecting for minerals will soon be greatly facilitated by a new system for airborne profiling of the terrain. This system will permit rapid collection of three-coordinate position information and provide data for mapping on-surface subsidence, for strip-mine monitoring, and for other applications. The system is scheduled to begin operating in the early 1980s (GS).

Improved mine safety is an important factor in materials technology. Probing radar has promise for predicting mine cave-ins and slides, and research will continue on safer hauling equipment, better emergency life-support systems, and new rescue technology to enable the mining industry to meet increasingly stringent safety standards (BM).

A need exists for more adequate data and more refined assessments of a number of environmental, health and safety problems associated with minerals extraction; in particular: the effects of mining on surface and ground-water systems; the planning and design of mines, including reduction of health and safety hazards; waste-disposal systems; the effects of blasting; the economic effects of environmental and occupational safety regulations; pollution abatement; and technologies for land reclamation (BM, GS).

New technologies developed in marine geology and geophysics will be used in the near future to explore the continental margins. The information will be used to assess the ocean's mineral, petroleum, and gas potentials, which may be vast (NAS 1). The technologies, for example, of multichannel seismic reflection systems, submersibles, and new drilling methods, are already available and will be used to penetrate more deeply into the oceans and bottom. Because deep sea mining is nearing reality, it would be helpful to establish an international legal framework—particularly for exploitation beyond national jurisdictions (NAS 1, State).

The issue of scientific research and resource development at sea seems certain to be of particular concern during the next five years. In addition, remote sensing of land resources by satellite is raising questions of national security and national sovereignty. These issues will continue to be discussed in international forums during the next five years. Improved scientific understanding of the oceans and our ability to monitor their changes should help to reach agreement on international ocean management policies. The policies should ensure the equitable global access to the ocean's mineral resources, while conserving the marine environment and its living resources (NAS 1, State).

CONSERVATION

Conservation is needed to reduce loss of materials at all stages of the production cycle, from mining and extraction (tailings and slags) to product use (wear and corrosion) to ultimate disposal. Estimates of loss for common metals range from one-half to three-quarters of the amounts that enter the cycle. In addition to recovery efforts at the extraction and processing stages, three of the potentially most effective means for conserving materials are improvement of product durability, substitution, and recycling (NAS 6).

Improved durability could effect large savings, for the processes of corrosion, fracture, and wear cause materials losses of $70 billion per year in the United States. Research is underway aimed at a better understanding of the fundamental physical and chemical mechanisms that affect durability in order to improve the performance life and quality of various classes of materials. In particular, new methods for detecting wear and new surface treatments show promise of substantially reducing materials losses (USDC, DARPA).

In principle, considerable savings could also result through recycling of materials, which permits the recovery of some of the energy used in production and reduces harmful environmental impacts. Industry already recycles large amounts of waste, scrap, and discarded products. The development of lower cost technologies that recover materials for reuse or for more efficient conversion to chemicals or fuels is an important objective, since such technologies would encourage more widespread recycling (NAS 6).

SUBSTITUTION

Conservation often comes from substitution of one material for another. Here the motivation to change usually arises from such economic consideration as the cost of materials. During the next five years, substantial efforts may be made to develop substitute materials (e.g., high-strength polymers and ceramics) for energy-intensive or scarce materials (NAS 6, NSF). Development will continue on the use of platinum-coated parts as a substitute for whole platinum, on the use of recycled materials in asphalt pavement, and on the substitution of iron-aluminum alloys for stainless steel (BM).

Because composite materials are often stronger, lighter, and more durable than conventional materials, they can contribute greatly to materials savings. In order to increase industrial use, efforts to reduce costs, to identify causes of failure, and to develop more effective and reliable testing and inspection methods are certain to continue (USDC).

Before the end of the century there may be shortages of organic as well as inorganic raw materials, particularly those that must be obtained from foreign sources. Rubber could become a scarce and uncertain commodity in the near future. A large number of industrial products, including pharmaceuticals, fertilizers, and pesticides, are derived from petroleum and are therefore expected to rise steeply in price as petroleum becomes more scarce. Therefore, the feasibility of using organic materials extracted from domestic plants will no doubt receive increasing attention during the next five years. At present, research on the use of renewable substitutes focuses on non-commercial wood products and wild plants that grow well on poor scrubland. However, a strong shift from nonrenewable to renewable resources in the future could create land-use conflicts. In addition, intensive cultivation of plants for use of the materials they contain might require large amounts of such nonrenewable resources as fertilizers and pesticides (NAS 6, NSF, Guither).

PROCESSING

During the past half-century, research and development in materials processing have led to continuing refinements which provide a good base for further progress in the next five years. The earlier accomplishments included automatic gauge control, electronic inspection of bars and tubes, directional solidification, precision casting, and cast-iron technology. For the near future advances are anticipated toward such industrial objectives as the production of superplastic metals using metal powders, ion implantation, the laser and electron beam treatment of surfaces to improve the wear resistance of metal parts, the development of high-speed metal removal processes, and the application of technologies from computer-aided design and computer-aided manufacturing to produce parts in relatively small batches. Current efforts are expected to aim at developing advanced processing systems that can reduce environmental and occupational safety hazards without adversely affecting materials production (NAS 6, BM).

Metallurgists do not expect to discover broad new classes of alloys in the near future. Rather, they envision that the properties of metals will be improved by modifying their internal structures through more precise control of the steps in fabrication, especially where deformation is involved. One example is the high-strength microalloy steels, which may be used increasingly in automobiles because they save weight (NAS 6).

As mentioned in the preceding section on Energy, controlled solidification of nickel-based superalloys has led to the production of single-crystal turbine blades and vanes. These components are likely to be demonstrated in engines within the next five years and are expected to extend their performance life and efficiency (NAS 6).

Synthetic polymers—plastics and synthetic rubber—are the fastest growing class of materials. Efforts are expected to continue to develop low-cost polymer materials with such improved properties as lightness, strength, flexibility, and resistance to heat (NAS 6).

Ceramics also offer great technological challenges. For instance, silicon ceramics may eventually replace superalloys in gas turbines and may also be used to build heat exchangers. These applications will permit higher operating temperatures than in those where metals are used and greater efficiencies than are now common in energy-conversion devices. Significant progress toward solving the problem of failures by brittle fracture that now limits the use of silicon ceramics may occur during the next five years. Intensive studies will be conducted on the synthesis of silicon ceramics with unique properties suitable for use in high-temperature structural components, refractories, and optical and electronic devices (NAS 6, NSF).

Because of many factors—richer ores, cheaper energy, cheaper labor, tax advantages, and less strict regulations on pollution and occupational health and safety—companies in the United States and other nations will be tempted to shift basic materials extraction and processing operations overseas during the next few years. The negative impacts of this possible trend must be assessed. They include loss of jobs in the domestic materials industries, greater pressure on the balance of payments, and uncertainties in deliveries of materials (NAS 6).

3. TRANSPORTATION

Some Problems Are:

- How to improve existing modes of transportation to meet the rising costs of fuel and the requirements related to environment, health, and safety.
- How to adapt the Nation's transportation systems to demographic changes and to changes in the character of cities.

Some of the Opportunities for Using Science and Technology Are:

- To use new materials, microcomputers, and other innovations to design more fuel-efficient, environmentally acceptable, and safer automobiles.
- To explore the feasibility of new, energy-efficient, urban transportation systems.
- To develop transportation systems for the special needs of the elderly and the handicapped.
- To incorporate advances in electronics and space technologies into the design of safer, more efficient aircraft.
- To exploit advances in electronics to substitute communication for transportation, where feasible.

OVERVIEW

During the next five years, the Nation will face the challenge of moving an increasing number of people and a larger volume of goods at a time when traditional transportation fuels will become steadily more expensive and harder to acquire.

During the last 150 years, first the railroads and then the private automobile and motor freight have enabled the Nation to improve its standard of living. Now there are indications that the era of transportation may be coming to a close, although this question is still a controversial one. Already we are replacing costlier modes of doing some things—driving to the bank, for example—with such newer, more efficient technologies as electronic funds transfer (EFT) systems. The possibility of electronic mail and the increasing use of telecommunications and computers are additional evidence that transportation, as a solution to many problems, may be giving way to communication technologies. This gradual shift will certainly continue during the next five years and into the longer range future. Certainly it will cause changes in transportation modes. However, because it will also facilitate decentralization, it may not reduce total transportation needs substantially (NAS 4, DOT, Dunn, Eberhard).

AUTOMOBILES

For most Americans, transportation means their own automobiles. But much of American industry and commerce depends on different transportation systems—trucks, railroads, airplanes, and ships. All modes of transportation are having to adjust to increased awareness of environmental impact and an enormous rise in fuel costs. In addition, certain transportation systems have undergone specific changes—for example, safety and fuel regulations for automobiles and Federal deregulation of airlines. Since many of these trends can be expected to continue, improved fuel efficiency will be a key issue for all transportation modes in the next five years (DOT).

The Department of Transportation, in partnership with industry, intends to undertake basic research in automotive technology so that a "socially responsible" vehicle—one that emits less pollutant, operates with greater fuel efficiency, and is safer for its riders—will one day be the norm. In particular, improvement in fuel economy is a top priority, and the Department's Integrated Vehicle Systems Program is evaluating advanced technology aimed at this goal. Materials substitution—replacing heavy metal with lighter materials—promises to lighten the automobile, thereby improving fuel economy. Vehicle safety is another priority; for example, the use of microprocessors in individual vehicles may be able to warn the user of impending mechanical and safety problems (DOT).

Safety and fuel economy are, of course, related to the condition of the highway system; the U.S. system is wearing out and needs rehabilitation. Using wastes and such extenders as sulfur to build highways promises cost savings. But protecting the large construction investment will also require determining the appropriate loading level of large vehicles. Efforts to solve the problem of relieving urban congestion in order to provide a better driving environment may also yield solutions related to safety and fuel economy (NAS 6, DOT).

URBAN TRANSPORTATION

The energy crisis of 1979 once again renewed interest in urban transportation systems. In response, the Department of Transportation, with the Department of Energy, is working to develop more energy-efficient and environmentally acceptable mass-transit vehicles. Another program of the DOT, the Downtown People Mover program, is a national demonstration of fully automated systems; it can lead to improved traffic circulation and distribution in center cities, better serving the needs of the elderly, the handicapped, and other groups (DOE, DOT, Eberhard).

Analyses of recent demographic data predict general trends that have important implications for transportation. In particular, these analyses forecast a rapid increase in the part of the population that is more than 75 years old. This trend may make it desirable to develop policies in the next five years for shaping the manmade environment. For example, the design of urban transit systems to meet the limited physical abilities of the elderly could receive increased attention (Eberhard, VA).

Longer life expectancies will lead to an increased number of small households composed of elderly couples or elderly people living alone. The rate of household formation will continue to exceed greatly the rate of population growth, with ill-understood effects upon the need for both transportation and housing services. Studies are likely to result in better understanding of these trends (NAS 7).

Cost-efficient urban transit requires populous urban centers, and demographic data indicate a shift from high-density area (the cities of the Northeast) to low-density areas (the Southwest). This population shift may entail a greater use of the private automobile and a reduction in the financial support for mass transit in those older metropolitan areas that are losing population (NAS 7, DOT).

AIR TRANSPORTATION

Air traffic grew without precedent in the latter half of the 1970s, and along with it came an increased concern about safety. In order to meet the increased air traffic demands that will come during the next two decades, programs are being initiated by the Department of Transportation to improve air traffic control and navigation capabilities by employing integrated circuits, minicomputers, high-speed microprocessors, and solid-state radio-frequency technology (DOT).

The National Aeronautics and Space Administration plans to continue research to help maintain U.S. technological leadership in aircraft design to benefit civilian and military aviation. The primary objectives for design are safer, more fuel-efficient, and environmentally acceptable aircraft; in civil aviation the needs are efficiency, noise reduction, and safety; and in military aviation the primary needs are integration of flight and engine controls, flight testing of advanced configurations, and development of a broad data base for use in future aircraft design (NASA).

4. SPACE

Some Problems Are:

- How to use, for greatest public benefit, the scientific research knowledge and technological capabilities derived from two decades of space research and development.
- How to decide in which directions to extend space research and development to get the greatest scientific, technological, and social return.

Some of the Opportunities for Using Science and Technology Are:

- To develop better vehicle- and satellite-borne instruments for obtaining information that will deepen our knowledge of the universe.
- To make the best use of remote-sensing satellites to obtain needed information about the earth's natural resources, its energy balance, its climate patterns, and its oceans.
- To continue research and development for improved space transportation and space data services.

ASTRONOMICAL RESEARCH OPPORTUNITIES

As the wealth of data returned by probes of Saturn and Jupiter clearly shows, space science and technology provide unique opportunities to study other planets and thus perhaps to learn more about the remote history of our own. But space itself can also be regarded as an excellent facility for making astronomical observations. Virtually all of our knowledge of objects in the universe beyond the earth—of distant stars, galaxies, black holes and quasars, for example—must be derived from observations of electromagnetic radiation (including light) that emanates from those objects. The ability of earth-bound telescopes to see distant objects clearly is limited by the scattering of light as it passes through the atmosphere. Electromagnetic radiation of all other kinds, except for a portion of the radio frequency spectrum, is entirely blocked by the atmosphere. Hence observations over the entire spectrum—in order to observe the broadest possible range of celestial phenomena—require that measurements be made from beyond the earth's atmosphere (NAS 3).

During the next five years, several new satellite-borne facilities will increase our ability to observe celestial radiations in different parts of the electromagnetic spectrum. In 1981, the Infrared Astronomical Satellite is scheduled for launching as a joint undertaking of the United States, the United Kingdom, and the Netherlands. The launching of the space telescope scheduled for 1983 will be a particularly significant event, since it will permit observations, without interference of the earth's atmosphere, of visible, near ultra-violet, and near infrared radiations. The development of improved facilities for x-ray and gamma-ray astronomy is also anticipated. Observation of these radiations provides information about highly energetic astronomical processes. Design studies are well along for an Advanced X-Ray Astronomy Facility (NAS 3). The overall design features of an Orbiting Gamma Ray Observatory have been completed and the observatory proposed as a new space science start for Fiscal Year 1981.

TERRESTRIAL OBSERVATIONS

The National Aeronautics and Space Administration has three programs designed to continue and expand the applications of space science and technology for terrestrial purposes during the next five years: (1) a study of the earth, using remote-sensing instruments carried by satellite, to understand its environmental characteristics, assess its surface characteristics and its resources, and develop a model of its changing features; (2) a program to improve satellite communications technology; and (3) a demonstration of the study of materials processing in a weightless environment (NASA).

The National Oceanic and Atmospheric Administration (Department of Commerce) has been designated by the Carter Administration as the operational manager for all U.S. Government ocean and land remote-sensing activities, including programs associated with Landsat, which has demonstrated the value of multispectral, synoptic, and repetitive views of the earth. The U.S. Geological Survey, in cooperation with NASA, intends to make use of refined remote-sensing devices that can more precisely map the earth by revealing small-scale features and provide more information useful to agriculture and the management of water resources. The cooperative effort also will probe the land mass for fuels, minerals, and geothermal energy sources. It will scan the atmosphere to chart the global energy cycle and the natural fluctuations and manmade modifications of climate (GS).

Remote sensing from satellites will also soon provide worldwide information on surface currents and temperatures, wave conditions, surface pollutants, and biological productivity of the oceans. Satellite altimeters can measure changes in the sea level, while ocean buoys that sink to predetermined depths are expected to furnish information about the three-dimensional flows within the oceans (NAS 1). The common need for ocean data for both civilian and military purposes has led the Carter Administration to propose the National Oceanic Satellite System (NOSS) as a new start for Fiscal Year 1981.

SPACE TECHNOLOGY

Maintenance of American leadership in space will be facilitated by the development of efficient, economical transportation modes. NASA's Space Transportation System has been designed as the primary means to fulfill the goal of making access to space more routine during the 1980s and 1990s, and will provide the foundations for the Nation's space requirements in the 21st century (NASA).

As presently designed, the full Space Transportation System comprises the Space Shuttle, Spacelab and the Upper Stages (which include the reusable Spacetug and the Orbital Transfer Vehicle). The Space Shuttle is the most important element of the system. Its versatility and reusability will open up a new era in expanding the uses of space for scientific, technological, and defense purposes. It will provide unique capabilities for placement, retrieval and in-orbit servicing of satellites, and delivery to Earth orbit of payloads and propulsive stages for higher altitude and planetary missions. The advent of readily available, economical transportation to and from low Earth orbit for automated payloads, as well as for scientists and other personnel, will revolutionize our concepts of using space and will expand the returns from space operations. The Shuttle's unique capabilities will not only lower the cost of space operations but will also lead to savings in the cost of payloads. These anticipated savings will result from repair and reuse of payloads and relaxation of weight and size constraints. The advantages offered by the Space Transportation System will enhance both the flexibility and the productivity of space missions compared to the capabilities provided by existing expendable launch vehicles (NASA).

The design certification review of the Shuttle's overall configuration was completed in April 1979, validating the basic technical soundness of the system design. The development program is in the final stages of ground certification testing of flight configured elements, and checkout of the first flight configured orbiter is progressing at Kennedy Space Center in preparation for the first manned orbital flight. Other elements of the program are progressing well: the engines, external tank, and solid rocket boosters required for the first flight are in the initial stages of processing at the Kennedy Space Center; all the facilities required there for that flight are complete and in place; and software validation is progressing. Production is underway on three additional orbiters with the objective of providing operational orbiters to meet the performance requirements of critical Department of Defense and civil missions. Decisions regarding the pace at which the development of additional components of the Space Transportation System are to be implemented will be made in the context of overall emerging space policy (NASA).

An additional objective of the U.S. space program is to reduce costs by increasing the efficiency of vehicle-borne data gathering systems. For example, NASA's Tracking and Data Relay Satellite System, due to begin operations in 1980, will provide a sixfold increase over the ability of present systems to monitor information from low-orbiting satellites. Refined instruments with improved optical tracking capabilities are being developed for use with remote-sensing satellites. And promising developments are underway to improve the navigational accuracy of planetary and deep-space probes and increase the reliability of the telemetry systems which they use to transmit data back to earth (NASA).

5. AGRICULTURE

Some Problems Are:

- How to maintain high levels of agricultural productivity, given rising costs and diminishing supplies of energy, water, materials, and land.
- How to maintain productivity by means that will be environmentally acceptable and profitable to farmers.
- How to ensure that adequate, usable water supplies continue to be available.

Some of the Opportunities for Using Science and Technology Are:

- To reduce agriculture's heavy dependence on fossil fuels by means of conservation, improved management practices, and the development of ways to use alternative energy sources, principally solar and biomass energy.
- To gain knowledge of how changes in energy availability and use affect all aspects of agriculture, from farming to marketing and distribution.
- To conduct research on such fundamental processes as photosynthesis, nitrogen fixation, and carbon dioxide fixation with the objective of breeding foodcrops that are more energy, water, and fertilizer efficient, and which are more resistant to pests.
- To improve the reliability of long-range weather forecasting to permit better agricultural planning.

OVERVIEW

Agriculture (including food production, processing, storage, transportation, distribution, and marketing) is the Nation's largest industry, accounting for about a quarter of the total Gross National Product. It employs 17-20 million people, and its current exports of nearly $30 billion a year are a primary foreign trade asset (Guither). Historically, U.S. agriculture has been characterized by high rates of growth in productivity. But the rising costs of land, labor, capital, and energy, and the costs of protecting the environment now threaten to end that long trend. U.S. agriculture has three key problems: (1) how to reduce future energy requirements in the face of higher costs and possible shortages; (2) how to increase its current high productivity; and (3) how to reach its objectives without adversely affecting environmental quality (Guither, USDA).

ENERGY-RELATED CONSIDERATIONS

The Nation's food production and marketing systems now account for about one-sixth of its total energy use. Agriculture's dependence on fossil fuels grows because, so far, it makes economic sense; farmers now spend 4 to 8 percent of their operating budgets on energy. This percentage is certain to increase as fuel costs soar (Guither).

The projected use of coal and synthetic fuels derived from coal as primary energy sources is likely to have important impacts on agriculture. Surface coal mining can take valuable agricultural land out of production and contaminate water required for irrigation. Increased burning of coal and synthetic fuels could cause serious changes in the climate and increase the prevalence of acid rain. These impacts need to be assessed in greater detail. In order to do so, improved information about the Nation's groundwater resources will be needed More refined knowledge about the earth's climatic conditions and the climatic and environmental effects of increased coal burning will also be required (GS).

A widespread move to solar energy for heating, drying, and irrigation could make agriculture more energy-efficient. Using agricultural waste products for biomass conversion on farms is a particularly attractive possibility, since it could reduce direct oil use without increasing costs for transporting fuels. The possibility of obtaining synthetic fuels and industrial chemicals from crops will receive considerable attention during the next five years and will present new challenges to American agriculture. For example, alcohol, distilled from farm products, yields gasohol when blended with gasoline. However, if in the future a significant amount of available agricultural land were used to produce crops for energy and materials-substitution purposes, severe pressure would be placed on the food production system. For that reason a good deal of attention is being paid to the efficient use of agricultural waste products and of such plants as guayule and jojoba, which can grow in otherwise unproductive land, for these non-food purposes (NAS 2, 6; USDA; USDC; NSF; Guither).

SELECTED RESEARCH TRENDS

Plant scientists have made appreciable gains in understanding plant variation, the movement of nutrients across membranes, the process of photosynthesis, and the factors that regulate plant growth. Application of this fundamental knowledge to agriculture is expected to lead to increased productivity and reduced dependence on chemical fertilizers and pesticides. Some of the most promising fields of scientific inquiry that will be pursued during the next five years are described below.

Photosynthesis

Present efforts focus on gaining an understanding and increasing the efficiency of photosynthesis of crop plants. This line of research aims to develop crops that can make more efficient use of solar energy. One promising line of inquiry focuses on converting the kind of metabolism shared by potatoes, soybeans, and most other crop plants, sometimes called C_3 metabolism, to the more energy-efficient type, C_4 metabolism, that is characteristic of certain other plants, for example, sugar cane and maize (NAS 2, USDA, NSF).

Nitrogen Fixation

Plants can obtain the nitrogen they require only from the soil. However, certain microorganisms that live freely in the soil can make use of, or "fix," nitrogen directly from the air. Some species of nitrogen-fixing bacteria live in a symbiotic relationship with certain plants (primarily legumes, including clover, peas, and soybeans) with the result that the plants themselves can make indirect use of nitrogen from the air. Recombinant DNA techniques provide the potential for producing more effective nitrogen-fixing bacteria. These techniques may also make the breeding of nitrogen-fixing plants possible. Since grains furnish much of the world's food, particular interest focuses on efforts to develop plant-bacteria symbioses that could fix nitrogen for grain crops. Similarly, several approaches are being explored to improve the nitrogen fixation that blue-green algae provide in rice cultivation (NAS 2).

Plant Breeding

Recent advances in plant tissue culture and recombinant DNA research provide the basis for new genetic technologies. Over the next five years, these techniques may be used to breed plants for such specific characteristics as increased yield, improved cold hardiness, drought tolerance, resistance to disease and insects, salt tolerance, efficient nutrient use, and high nutritional value (NAS 2, USDA, NSF).

Pest and Disease Control

There is now considerable evidence that some chemical pesticides have adverse cumulative effects upon populations of organisms, such as animals and humans, other than those for which the chemical is intended. This finding has led to increasingly stringent restrictions on the use of those pesticides. As a result, the next five years will see intensified research on several means of resolving the sometimes conflicting needs of disease and pest control and general environmental protection. Efforts will be directed toward pest-management systems that use a minimum of chemicals and a variety of techniques and methods to control pest populations, selective, biologically based interference with the reproductive processes of pest species, microbiological and other natural biological agents for pest control, and breeding of crops for pest resistance. Progress should also be made in understanding the chemical basis of plant resistance and to identify chemicals that make a plant unattractive to insects or pathogens (USDA, Guither).

PRODUCTIVITY

During the next five years, the need to conserve energy, water, and materials will focus increasing attention on the difficulty of increasing agricultural productivity. Detailed studies need to be carried out on the economic impact of energy policies on agriculture, the most efficient size for farms, and the effects on agriculture of such practices as integrated pest management, double cropping, and computers as an aid to management (Guither). It is also feasible—and necessary—to assess more precisely the effects of environmental regulations on food production, and to develop a better data base for more efficient regulatory policies (USDA).

More efficient use of farm land can also increase productivity. One way is to retain "prime" land in agricultural production (i.e., to prevent prime land from being sold for other purposes), since its continued loss at the current rate may eventually lead to its replacement with less productive land. If prime land is not preserved, farmers may have to spend more energy in obtaining the same production from their remaining acres or in bringing marginal land into production (NAS 6, Guither, USDA).

The study of weather and long-term climatic changes and the application of the resultant understanding to the problem of improving agricultural production are potentially fruitful areas for international cooperation. Such cooperation facilitates information gathering on a global scale. There is insufficient knowledge of climatic processes for accurate weather forecasting. Reliable forecasts of weather for one growing season ahead would greatly improve agricultural planning, as would predictions of long-term trends. During the next five years, increased use of satellites and other remote-sensing devices is expected to reduce the uncertainties in short- and long-term weather forecasting. The combination of improved weather data with satellite-based crop surveys should also improve worldwide crop forecasting capabilities. The essential role of worldwide cooperation in such a scheme is clear (NAS 1, State, Guither).

6. HEALTH

Some Problems Are:

- How to understand the biological processes underlying specific noninfectious diseases.
- How to increase understanding of the biological and social bases of human behavior.
- How to increase awareness of the importance to well-being of environmental and lifestyle factors that are under individual control.
- How to establish a sound and rational scientific basis for environmental, health, and safety regulation.
- How to develop better, more cost-effective, health care delivery systems.

Some of the Opportunities for Using Science and Technology Are:

- To conduct basic biomedical research for the purpose of yielding fundamental knowledge of normal processes and pathological mechanisms.
- To conduct basic studies of the brain and nervous system as a basis for understanding neurological disorders, mental illness, and alcohol and drug abuse.
- To study social factors that determine substance abuse, in order to develop better diagnostic and therapeutic methods.
- To determine the effects of environmental, occupational, and dietary exposures to potentially hazardous chemicals and radiations.
- To focus particular attention on aging as a lifelong process.
- To conduct studies of health care delivery systems aimed at improving their quality, accessibility, equity, and cost effectiveness.

OVERVIEW

Many of the Nation's present concerns about health are the result of enormous improvements that have taken place since the start of the 20th century. These improvements are largely based upon past scientific achievements.

Patterns of illness have changed since 1900. Because older health problems have been eliminated, the importance of others that formerly constituted a minor source of morbidity and mortality has increased. Heart disease and cancer are now, for example, the leading causes of death in this country. During the early part of the century, advances mainly resulted from better sanitation and nutrition. Later, progress came about as infectious diseases were brought under control. Infant mortality rates declined sharply during the first half of the century and less rapidly since that time, and as a result concern with the incidence of childhood diseases has lessened considerably. Life expectancies in the United States have been extended, though at present they are not among the highest in the industrialized countries. These extensions, together with the declining U.S. birth rate, have markedly increased the average age of the American population and focused more attention both on the chronic diseases and disorders of middle and old age and on the nature of the aging process itself. For example, substantial decreases in deaths from strokes and heart attacks have been achieved in just the past five years (NAS 7, 8).

Many of the Nation's present health concerns are linked to lifestyles and to environmental factors which advances in biomedical sciences and technology alone cannot ameliorate. Accidents are the chief cause of death up to age 35. A significant fraction of all cigarette smokers ultimately die early as a result of their habit. Alcohol and drug abuse have become severe social problems. Chronic diseases such as hypertension, diabetes, emphysema, asthma, and mental illness pose serious threats to large numbers of Americans. Thus, future improvements in the health of the American people will be the result of several different efforts: continued improvements in public health, scientific research on the causes of specific diseases and disorders; improvements in the means for translating scientific knowledge into practical steps to promote health and prevent and control disease; identification and understanding of the effects on human health of chemical contaminants in foods, drugs, and the environment; and increased data on the links between health and behavior patterns such as smoking, diet, exercise, working, and coping with stress (NAS 8, ADAMHA).

The prevention of illness, including prevention through individual control of lifestyles, must continue to be a high priority. This is particularly so in view of the steeply rising costs of health care. During 1979 these costs were over $200 billion, or more than the cost of a month of labor per American worker. If general inflation were to proceed at a 9 percent annual rate and health care costs were to continue to rise at a rate 50 percent greater than general consumer prices, national health care expenditures would exceed 20 percent of the Gross National Product by the year 2000. A wide range of health-related problems will face the Nation during the next five years. A wide range of opportunities will exist for science and technology to deal with these problems. Thus the central dilemmas are these: How much are we as a Nation willing to pay for medical services? And what should our priorities for medical research and technology be? (Warner)

SELECTED BASIC RESEARCH TRENDS

Genetic Studies

For the past 35 years it has been known that genetic factors are transmitted from one generation of cells to the next in the form of molecules of deoxyribonucleic acid (DNA). We now know that for all species of higher plants and animals (including human beings), genetic information is carried from one generation to the next in the form of DNA. A central, long-range goal of molecular biology has been to understand, in detail, the sequence of mechanisms through which the information encoded in a particular type of DNA molecule is transferred into the structure of a corresponding protein, and thus, ultimately, how information transfer via DNA governs the development of all living organisms (NAS 2).

Occasionally a defect occurs in a DNA molecule—or is induced, perhaps by a molecule of a carcinogen or by ionizing radiation. The result is an alteration in the genetic information carried by the DNA, and, as a consequence, a mutation in the organism of which it is a part. Research on genetic mutations will continue during the next five years and is likely to yield important new knowledge. This research is indispensable to understanding how normal cells become cancer cells, though it is not possible to predict when it will yield insights directly applicable to the prevention and cure of the disease (NAS 8). In addition, research on genetic mutations will improve our understanding of human hereditary diseases of which more than 2,000 are now known. Some defects in gene structure and function may eventually be correctable, and progress toward this end is likely to occur during the next five years. In addition, the prospects are good for improving techniques to detect fetal genetic defects by amniotic fluid sampling (NAS 2, NIH).

Recombinant DNA methods, which have emerged as important laboratory tools within the past five years, now permit rapid advances in understanding basic genetic mechanisms. DNA molecules can be cut precisely into small pieces and spliced into bacterial DNA. Bacteria—and therefore the DNA they contain—reproduce themselves every few minutes, whereas cells of higher organisms have reproduction times that extend upward to years. Recombined DNA molecules multiply at the same rate as their host bacteria and reproduce themselves with equal fidelity. Therefore, it becomes possible to study the detailed reproductive mechanisms of precise, known DNA fragments on convenient time scales (NAS 2).

Since recombined DNA molecules reproduce themselves rapidly and faithfully, the technology also offers the possibility of large-scale production of biological chemical products for the treatment and cure of diseases. For example, the possibility of producing insulin by this method has now been demonstrated. Also, human interferon, a natural virus-fighting substance that is currently scarce and prohibitively expensive, has been synthesized in the laboratory. Commercial production of insulin of higher purity and at a lower cost than is now available also appears to be highly probable within the next five years (NAS 2, NIH, NSF).

Because recombinant DNA methods permit the precise manipulation of genetic materials, they raise important safety questions. For this reason, the National Institutes of Health has developed and issued guidelines on recombinant DNA research. Developed after extensive public hearings, these guidelines were intended both to encourage needed research and to insure that the public health and the environment will be adequately protected from risks. The effects of these guidelines on both the public health and safety and on scientific research will be monitored during the next few years (NAS 2, NIH, NSF).

Cellular Biology

The ability to carry out genetic studies in more complex cells, as well as the knowledge gained from the study of simpler cells, has stimulated progress in the related field of cellular biology. Of particular interest is the cell membrane, the boundary and point of interaction of the cell with hormones, drugs, bacterial toxins, and viruses. Uncovering the mechanisms of cell migration is central to understanding the movement of white blood cells in their fight against infection and the migration of cancer cells as they invade organs (NAS 2).

Immunology

Although molecular biology and cellular biology have been at the center of attention in biological research, other recent emphases in the life sciences have significant implications for public health. For example, recent progress in immunobiology has led to more rapid identification of microorganisms, better understanding of many disease mechanisms, and developing better preventive measures (Army, NIH). Advances in research on allergies, the most prevalent disorder of the immune system, have come rapidly in recent years. New discoveries have aided desensitization theory and offer therapeutic promise. Also as a result of basic research in immunology, medical technology can now achieve better tissue matching and offer improved treatments to suppress the immune system of patients receiving transplants. This research is also leading to improved understanding of autoimmune diseases, and could point the way to the development of vaccines for measles and hepatitis (NAS 2, NIH, VA).

The Aging Process

The changing age distribution of the American population has drawn attention to the lack of scientific knowledge of the human aging process. Basic and clinical problems likely to be studied in the next five years include changes in immune responses and hormonal secretions with aging, neurobiology of sleep and memory in the aged, and problems of drug therapy in the elderly (NAS 8, NIH, VA). Health and social services will have to be assessed, and possibly redesigned, to assure the maintenance of the functional independence of the elderly; a failure to maintain it seems to promote the disabling aspects of aging (NAS 8, NIH, VA).

Human Behavior

Studies of hormones produced in the brain, a relatively recent research interest, are advancing rapidly. These hormones appear to act on the brain in ways similar to the chemical substances that normally transport nerve impulses across gaps between nerve cells. The brain hormones are thought to influence sexual development, responses to stress, hunger and thirst, and possibly learning and memory. Among the hormones produced by the brain, the endorphins are of special interest. Endorphins have been found to be effective in relieving pain and inducing the sensation of pleasure. Studies of endorphins conducted during the next five years are expected to illuminate both normal and abnormal human behavior patterns (NAS 2, NSF).

Mental illness is among the disorders causing greatest concern in recent years. The rapidly growing body of knowledge about the brain and the nervous system makes it reasonable to expect some progress in the next five years toward the eventual development of improved treatments for many disorders: schizophrenia, mental retardation, and neurological disorders, as well as depression, learning disabilities, alcohol abuse, and drug addiction. Some drugs have already revolutionized the treatment of mental illness, but considerable dispute continues about why and how they work. Safe and reliable treatment dictates the urgent continuing need for research that can illuminate these questions and provide acceptable answers (NAS 8).

Increasingly, we have become aware of the crucial effects of the environment and behavior on disease patterns. In fact, modification of environmental and behavioral patterns may prove central to the prevention of many of today's prevalent diseases. Behavioral toxicology, a relatively new field, shows considerable promise of increasing our understanding of the effects of environmental contaminants on behavior. Alcohol abuse, long regarded as one of the more common, socially destructive types of human behavior, has only recently become a principal focus for research in the biomedical and behavioral sciences. Growing public alarm about drug abuse has also stimulated biological and behavioral studies. A better understanding of individual differences in susceptibility and of physiological self-control mechanisms will allow a concerted attack on alcohol and drug abuse and on other disorders of human behavior, such as addictive tobacco use and compulsive gambling (NAS 8, ADAMHA, VA).

Cigarette smoking is a contributor to 80 percent of lung cancers, as well as certain cardiovascular diseases. A 20-year study showed that between one-third and one-half of all cigarette smokers die prematurely because of their habit. Behavioral research in the next five years will focus increased attention on better ways to stop smoking and prevent relapse (NAS 8).

ENVIRONMENTAL CONSIDERATIONS

The environment, lifestyle (including cigarette smoking and the use of alcoholic beverages), diet and genetic factors play an important role in the major health threats to Americans. Present evidence indicates that cigarette smoking and diet are among the risk factors in cardiovascular disease and various types of cancer. There is little doubt that both avoidance and stopping of cigarette smoking will reduce the risk of cardiovascular disease and of lung, oral, and bladder cancer (NAS 8, NIH).

Epidemiological studies have been useful in delineating the risk factors associated with cardiovascular disease and some types of cancer, and often epidemiological studies offer the first indications of carcinogenicity for chemicals already in use in our society. However, for new chemicals, reliance on epidemiological studies would be inappropriate since the latent period for carcinogenic effects to humans would be 5 to 30 years or longer. Therefore, both laboratory tests using animal bioassays (generally mice and rats) and short-term in vitro methods should be the approaches for establishing the potential carcinogenicity of a chemical for humans (FDA, Seskin and Lave).

The increase in the development, manufacture and use of synthetic chemicals has focused attention on their potential toxic effects, and a need has arisen to find more expeditious and less expensive methods of evaluating their potential toxic effects including carcinogenicity. With regard to carcinogenicity, efforts thus far have involved in vitro tests of mutagenicity (since the capacity of a chemical to cause mutations correlates well with its capability to induce cancer in animals or humans), cell transformation and effects on chromosomes. Research in this direction is promising and will continue; of particular importance will be in vitro interspecies comparisons, including the use of monkey and human cells (FDA).

Dealing with the hazards of environmental contaminants is extremely complex because even when their effects are known, the determination of socially acceptable levels of risk involves questions of values as well as technical information. Furthermore, the long-range economic and social costs involved in enforcing regulations to reduce contaminants below predetermined acceptable levels need to be determined. These aspects are detailed in the section on the Perception and Management of Hazards and Risks.

In studying air pollution, attention must be paid to interregional transport and transformation of fine particles; the fate and effects of air pollutants, especially trace elements; and the many scattered sources of pollution. Contamination by waste water and solid waste may not be as widespread as air pollution, but they present comparable problems. Partially as a result of the Three Mile Island nuclear accident, renewed attention is being given to health effects from exposure to low-level ionizing radiation. But there are other, more significant sources of radiation in the environment besides those that are associated with nuclear reactor failures, including diagnostic x-rays and radiations from building materials. Adverse environmental effects are also associated with virtually all of the energy technologies that the Nation must rely on for the remainder of the century—conventional combustion of fossil fuels, coal liquefaction, and gasification, as well as nuclear energy. These effects must receive closer scrutiny during the next five years (NAS 9, USDC, DOE, FDA, EPA, NRC).

HEALTH CARE DELIVERY

Innovations are anticipated in the next five years in the delivery of health care. Perhaps the most promising approaches, besides those that concentrate mainly on preventive medicine, are group medical practices and health maintenance organizations. While these forms of practice are growing, the National Health Service Corps is extending primary health care to underserved rural and low-income urban areas; nurses and paramedics are being specially trained to provide care in these areas. More effective health care for the young and the aged may result from analyses now underway on institutional and organizational changes in health services. Systematic comparison of alternative health care delivery systems can assist policy choices in the years ahead (NAS 8, NIH, VA).

RESOURCE ALLOCATIONS

Despite the enormous strides that are being made in understanding diseases and disorders and improving the delivery of health care, and despite the splendid opportunities that exist for advances in the future, a heavy burden of illness remains to the Nation. This burden can be measured by mortality rates. It can also be assessed in terms of the suffering and debilitation of afflicted individuals, the aggregate social effects of their illnesses, and in terms of such economic effects as productivity loss and the total cost to the Nation of the health care system itself. Measurements of mortality rates are relatively straightforward, and the existing data are adequate. Defining and measuring social and economic costs are difficult, but during the next five years there are some grounds for expecting that such indices will be refined and may become usable for allocating medical resources more wisely to areas creating the highest social costs (NAS 8, NIH).

Making meaningful comparisons of the individual, social, and economic burdens of illness are even more difficult since such comparisons involve value issues as well as technical information. Since our culture has traditionally placed a supreme value on human life, it is morally repugnant to many persons even to raise the question of tradeoffs among individual, social, and economic costs and benefits as long as there is even a remote opportunity to ease the suffering of an afflicted individual. Yet if we as a Nation are to maximize opportunities for future advances and make the wisest present use of our medical resources, it will be necessary to face up to the difficult and often cruel dilemma of establishing realistic priorities (NAS 8, NIH, VA, Warner).

7. THE ELECTRONIC REVOLUTION

Some Problems Are:

- How to use the capabilities of computer and communications science and technology to serve a wide range of commercial, public, and personal needs.
- How to resolve the social, ethical, and regulatory issues that are emerging as a result of the electronic revolution.

Some of the Opportunities for Using Science and Technology Are:

- To develop better computer languages and programming theory to make the best use of the ever-increasing level of hardware capabilities.
- To find new and better computer-communications systems to help improve productivity in all sectors of the Nation's economy.
- To assess the long-range effects upon society of widespread adoption of computer-communications systems.
- To continue research and development to reduce the costs and increase the speed and usefulness of information handling capacities of computers.

OVERVIEW

The electronic revolution is bringing about an information revolution and it has a dual foundation: computers and telecommunications. The computer's ability to manipulate and process information is the precipitating cause of the revolution. But having the capacity to store and handle information becomes more valuable when the information can also be communicated. The telephone cables, microwave systems, and satellites are the transmission analogs to the transportation grids and modes of the industrial economy. Whereas mobility in physical space is achieved through roads and railways, mobility of information is gained through the telecommunications network (NAS 4).

Electronic computers, once the exclusive province of advanced research laboratories, have now penetrated U.S. factories, offices, and homes. Computers have become the means to other innovations and knowledge and, as a result, affect virtually all social strata. Exploring and expanding the technical and scientific boundaries of computers are key undertakings of the future, and as they occur, the convergence of computer and communications technologies will accelerate and will permeate more social layers, reaching more and more people. New methods of communications techniques such as modulating laser emission, digitally encoded telephone communications, and the use of fiber optics will become more economical, easy to use, and widespread (NAS 4, USDC).

COMPONENT AND SYSTEMS RESEARCH AND DEVELOPMENT

Semiconductor chips are the essence of high computer technology. The tremendous progress of computers during the past decade has been based on the increasing complexity (number of transistors) and decreasing costs per chip. This progress is expected to continue and become even more cost effective. For example, from 1971 to 1978 the number of bits of information per chip increased from 1,024 to 64,000. By the early 1980s, 256,000-bit memory chips are possible; and by the end of the decade, million-bit memory chips are anticipated (NAS 4).

Microcomputers have evolved at a comparable rate, integrating as many as 30,000 transistors on a chip with steadily declining cost per unit operation. Progress in capability, cost, and application is expected to continue over the next five years. Computers now under development will store much greater amounts of information at a fraction of current costs. By the mid-1980s microcomputers will undoubtedly extend the range of economical computer applications and become the principal computational workhorses of the future. As chip technology continues to evolve, the distinction among micro, mini, and large computers will depend less on size and storage capacity and more on how they are used (NAS 4).

While cost and size have diminished over the years, computation speed has increased substantially. Further increases in speed are expected, but they will come at a decelerating pace unless new technology is introduced. Several promising alternatives are possible, and superspeed logic technology may come into use during the 1980s (NAS 4).

Reductions in computer size and weight and increases in computer capabilities also dictate increasing use. Computers now under development will store much greater amounts of information at less than 1 percent of current costs. Constraints on the development of computer technologies include the growing cost of implementing software and a lack of trained personnel (DARPA).

As hardware costs steadily diminish, programming costs—the writing of a set of instructions to tell the computer what to do and how to do it—become an increasingly large component in computer operations. Advanced software engineering has the potential of lowering computer programming costs by further developing and utilizing first principles that allow programming to be approached systematically, organized in more standardized ways, and reduced in its burden of redundant details. Related goals are to find ways of using computers to check the internal consistency of large programs, pinpoint discordant details, and define formal techniques to prove programs correct or prevent the generation of incorrect programs. Progress toward these goals has been limited but will likely increase during the next five years (NAS 4).

There is little apparent progress concerning developments associated with research on alternative programming languages. Highly detailed programming may eventually be replaced by more abstract languages that can be transformed into a more efficient machine code Similarly, there is a void in developmental progress concerning improved techniques for writing programs that control many simultaneously active computer tasks (NAS 4). The growing costs of implementing software and a lack of adequately trained specialists will also continue to impose constraints on the development and implementation of computer technologies (DARPA).

SYSTEMS APPLICATIONS

Current trends are toward decentralized computer systems with the user terminals located as close as possible to the actual business locations. These mini-systems are, or can be, interconnected so that each node in the system can command the computing resources in every other node. The interconnected network itself becomes a giant computer which can be accessed from any one of the nodes. This trend, it appears, will continue in the future. The convergence of computers and communications has contributed to the development of new technologies involving data networks; e.g., specialized satellite capabilities, digitally encoded telephone communications, and high information rate optical fiber communication (NAS 4).

Computer technology is being used more and more to assist many aspects of American commerce and industry, such as computer-assisted design and manufacture, which promises improvements in small-batch manufacturing. Planned advancements in domestic communications satellites, as well as other modes of transmission media, will further the capability to link electronic devices on a national network basis. Potential applications could enhance city, urban and small town planning and management (USDC, Eberhard). Microcomputers, video storage devices, and word processors, used in educational settings, can supplement regular classroom instruction, serve as devices for drill and practice, help to design new tests, and assist in identifying student needs more efficiently (NIE). Computer technology is being applied to complex information storage in digital form, which, for example, directly relates to spatial data processing that assists in water management, land-use planning and the preparation of environmental impact analyses (NAS 4, GS).

As these examples suggest. computer and communications technologies provide opportunities to accelerate the transfer of and usefulness of scientific knowledge to urban users. Microprocessor chip technology will influence many aspects of the city of the future, including its greater use in traffic control, financial management, and health care delivery. Advances in domestic communications satellite development will not only help cities share management information, but can on a national basis enable the accelerated development of emergency communications network capabilities to deal with disasters (Eberhard).

POLICY ISSUES

Information systems that combine computer and communications capabilities raise a particular set of national policy issues. Telecommunication networks are traditionally regulated by the Federal Government. But the question as to whether and how regulation should be extended to include information systems is still under debate. The question of Federal regulation will also be raised by the increased use of electronic message services (EMS). At present, relatively homogeneous groups of users are able to send each other short, typed messages through time-shared computing services. However, a shift from the use of hand-carried mail to electronic mail will become feasible in the next decade. If EMS is considered a communication service, then, according to present law, it must be regulated. Then, should the U.S. Postal Service be regulated? And if it is permitted to offer EMS at prices below cost, what will be the effects on private industry? A more general policy question that needs to be addressed in the context of computer and communications developments is how to balance the needs of users against the services that can be provided on an equitable basis in a competitive open market environment (Dunn).

The rapid advances which are underway in telecommunications have led to overcrowding of the radio-frequency spectrum and satellite orbit space. Despite recent international affirmations of the principle of free flow of information and ideas, some countries are urging controls, and no doubt will continue to do so. A number of them have adopted national legislation to regulate the flow of data that might affect privacy or other rights of citizens. These developments, related to new technologies, are becoming important determinants which must be factored into U.S. foreign policy considerations (USDC, State).

Perhaps the single issue related to information systems that looms largest in the minds of Americans is privacy and the need for standards that ensure fairness to individuals in the use of recorded information about them. This problem has arisen because of the financial records held by banks and creditors; the increased personal information now collected; and the automated recordkeeping and dissemination technologies that make it possible to collect and handle large quantities of data efficiently and economically (Belair).

Through a series of statutes, Federal policies have been established to ensure that the workings of the data systems are publicly known; that data are as accurate and complete as possible and can be disseminated only for "legitimate" purposes; and that individuals should be able to see and correct their files. Thus, a framework for protecting information privacy has been created at the Federal level and partially implemented at the state and local levels. Implementation in the private sector is just beginning (Belair).

Since 1967, more than 50 congressional hearings have sought principles to guide, and make publicly acceptable, further growth of personal data files. The policy being developed seeks to help people live comfortably with their records, rather than to limit the growth of recordkeeping itself (Rule). As financial data services become increasingly automated during the next five years, attention is likely to focus on whether individuals have the right to conduct their financial affairs in secret or to communicate by encrypted data flows that cannot be decoded (Dunn).

In the 1980s the concerns about information privacy are likely to continue and perhaps intensify. There will be a continuing need to enforce the information-privacy standards, monitor developments in information technology which could affect the individual's privacy, and formulate improved disclosure safeguards (Rule).

8. THE PERCEPTION AND MANAGEMENT OF HAZARDS AND RISKS

Some Problems Are:

- How to understand natural hazards better and find better ways to predict and mitigate their effects.
- How to understand the hazards of contamination in the environment and in food, and how to eliminate or mitigate these hazards in order to establish balanced regulatory policies.
- How to improve public understanding of tradeoffs among the costs, risks and benefits inherent in modern society.

Some of the Opportunities For Using Science and Technology Are:

- To pursue research aimed at understanding and predicting several kinds of natural hazards.
- To learn what hazards are produced by what technologies and to eliminate or reduce the hazards.
- To develop the tools necessary to detect the presence of hazards and for monitoring their movement in the environment.
- To assess the effects of particular substances on human health and on the environment.
- To develop better ways to handle existing hazardous solid waste disposal sites and fluid waste disposal streams.
- To develop better methods of risk assessment and better understanding of how risks and benefits are assessed by society.

- To improve the effectiveness of participation, by the affected public, in decisions in which the public may be at risk or at benefit.

OVERVIEW

Advances in technology, as has been demonstrated in recent years, are often accompanied or followed by the emergence of new dangers to the environment and hazards to human health and safety. The adverse effects have been mentioned in passing in earlier sections. Here they are addressed as the primary concern.

Manmade chemicals in the form of fertilizers and pesticides ensure regular and bountiful harvests, but some of these chemicals are also harmful to human beings and the environment. The energy sources which U.S. industrial society relies on to produce goods, and to transport goods and people, simultaneously pollute the air. The combustion of coal produces air pollutants, results in acid precipitation, and contributes to the global buildup of carbon dioxide. The effects of this last circumstance are not yet fully understood, but the accumulation of carbon dioxide in the atmosphere could generate long-range climatic changes. Nuclear power, meanwhile, confronts us with hazards from reactor operation, disposal of high-level radioactive waste, and proliferation of nuclear weapons. Still not adequately assessed are the health effects related to exposure to low-level ionizing radiation. And our transportation system contributes its share of hazards from the fuels it burns and the risks arising from the sometimes marginally safe methods it employs in carrying an increasing volume of hazardous materials (NAS 9, USDC, DOE, FDA, DOT, EPA, NRC).

The use of science and technology is essential to help identify the hazards that they help create. Science and technology can also contribute to the reduction of these hazards. In the next five years methods of science and technology will be used increasingly to understand better, and to mitigate where possible, hazards of particular social concern.

TYPES OF HAZARDS AND RISKS

Natural Hazards

Methods of the geological sciences have been used for some time to survey the incidence, and mitigate the effects, of such natural hazards as earthquakes, volcanoes, landslides and land subsidence. More recently, interest has grown in predicting occurrences of these phenomena, particularly earthquakes, by identifying and refining instruments to measure sensitive precursor phenomena. Although progress has been somewhat slower than may have been hoped, these efforts will continue during the next five years and may yield insights that can improve their reliability. Development of the plate tectonics theory has provided a considerable impetus to earthquake prediction research, since it offers a means of predicting, with high probability, where some earthquakes are likely to occur. Efforts to refine our understanding of relationships between the movement of tectonic plates and earthquakes will remain a topic of research interest during the next five years. As earthquake prediction becomes more accurate, development of technologies to mitigate earthquake damage will become more feasible (NAS 1, GS).

Mining Hazards

The next five years will see continuing efforts to address the safety issues related to mineral extraction. In addition, research will continue on such subjects of environmental concern as the impact of mining on surface and groundwater systems; waste-disposal problems; the environmental effects of oil-shale development; underground disposal of mine wastes and tailings; and improving the technology for land reclamation (BM).

Toxic Substances

The introduction into the environment of synthetic materials, some of which are potentially hazardous, has required an expansion of research into toxic substances. Coordination between the research community and government regulatory units has been improved during the past few years, and training of toxicologists and epidemiologists who can detect, evaluate, and judge how to deal with hazardous substances has been accelerated. A greater degree of public understanding of the taxonomy of hazards from toxic chemicals is needed. The most prevalent hazards are: (1) occupational exposure, including inhalation, contact through the skin, and ingestion; and (2) population exposure—through air transport mechanisms, chemicals entering groundwater and eventually ending up in municipal water supplies and well water, and inadvertent incorporation of toxic substances into building materials with consequent exposure by inhalation, skin contact or ingestion. So far as the population is concerned, by far the greatest concern is with exposure to water-borne toxic chemicals. Hence, the most important data concern groundwater movement, which we need in order to choose the most suitable disposal sites in the future and to predict their further spread from existing sites or discharges (NAS 9).

Research and development are urgently needed both to stem the spread of toxic materials resulting from present and future industrial activities, and to provide us with means for assessing and coping with problems inherited from the past. These activities are essential because persistent chemicals such as polychlorinated biphenyls (PCBs) move out of fresh-water sediments and into the food chain, eventually to deposit in higher animals and humans. In the next five years, new technologies will be pursued to deal with chemical wastes that have already been dumped into landfills, lakes, and rivers (NAS 9, NSF).

The development of methods for detecting, sampling, and monitoring hazardous substances in the environment will also be pursued during the next five years. For example, methods are needed to identify and assay drug and pesticide residues, aflatoxins, and viral contaminants. Improvements will also be sought in bioassay methods used to determine effects. Toxicity tests of "realistic" exposures may be developed by 1985 to overcome the serious difficulty that now exists in establishing appropriate dose levels for the tests. Perhaps the primary problem related to chemical hazards is associated with their sheer number. There are so many chemicals that the costs of the animal tests needed to establish the hazards of low level exposures are very high. Thus there is an urgent need for advances in simplified screening tests (such as the Ames test or tests using human organ cells grown in tissue culture) which can be used to distinguish between chemicals that are likely to be exceedingly hazardous even at low levels and those whose probable effects on health are far less significant (NAS 9, FDA, NSF).

In the meantime, those current regulatory goals that are based upon detectable amounts of known toxic chemicals will have to be revised in the light of our ability to detect increasingly low concentrations. Thus, if refined analytical methods are to provide a basis for a balanced regulatory policy, it will be necessary to address the problem of how "zero" levels should be defined when they are used (FDA). When it is impossible or too costly either to remove a harmful agent from the environment or avoid it totally, we must encourage informed public discourse and take other necessary steps aimed at establishing socially acceptable exposure levels (NAS 9, NSF).

Solid and Water Wastes

During the next five years, science and technology can make appreciable contributions to three major objectives associated with solid waste disposal problems: first, to develop safe disposal practices, methods for managing large volumes of industrial and municipal wastes, and criteria for selecting appropriate sites for landfills; second, to develop the capability to dispose of many, if not all, wastes at sites near their sources; and third, to develop economically feasible resource recovery methods. One promising approach to the latter problem is to reduce the production of wastes by means of recovery and recycling during the industrial processes themselves. Another approach is to employ biochemical methods for conversion of solid wastes into such useful products as fuels, chemical feedstocks, proteins and alcohol (EPA, NSF).

Waste waters produced by the organic chemicals and textile industries typically contain high concentrations of toxic pollutants. A continuing research objective during the next five years will be to reduce the high costs of technologies for treating such toxic wastes in water as benzene, metals, and oxygen-bearing compounds. Recycling and recovery of toxic pollutants during production processes are an attractive possibility. However, satisfactory design and control technologies do not yet exist, and cost effectiveness has yet to be demonstrated (EPA, NSF).

Transportation-Related Hazards

Different forms of transportation create different types of environmental and safety problems. To minimize oil spills and disasters from hazardous materials carried by ships, it will be necessary to expand research into means of reducing accidents at sea, such as through development of advanced navigation systems. At the same time, high priority should be given to efforts aimed at developing techniques to quickly limit the damage done by spills. Research will also be needed into methods of preventing pipeline failures and of lessening the damage caused by those that do fail (DOT).

The expected growth in air travel over the next two decades may require extensive improvement of the Nation's air-traffic-control and navigation systems to minimize the hazards of aviation (DOT).

Safer streets and highways can result from motor vehicle safety studies, designs, and production, and also from better and more durable roads and improved highway design (DOT).

A pressing challenge facing railroad technology over the next five years will be development of means to transport radioactive and other hazardous materials safely. Also, improved road beds, equipment, and control systems are needed to make this energy-efficient mode of transportation safe and economical (USDA, USDC, DOT).

Ionizing Radiation

Many sources of ionizing radiation exist in the environment. Major reductions in the amounts of exposure can be made through reductions of medical and dental x-rays and better occupational control. In addition, some workers in the nuclear industry may be exposed to higher levels than background in the course of their work (NRC, USDC).

The effects of low levels of ionizing radiation on human health are uncertain, but extensive epidemiological studies to improve our knowledge are in progress. The source of the uncertainty about the effects of low level radiation is related to uncertainties in the linear dose-response hypothesis, which assumes that any increment in exposure produces an increase in health effects which is proportional to the percentage increase above normal background levels. The validity of this hypothesis remains a subject of considerable controversy. In addition, it is worth noting that most of the concern about exposure to low levels of ionizing radiation is associated with the operation of nuclear reactors. During the normal operation of such reactors, the levels of exposure of the population to ionizing radiation are below natural background radiation. In particular, they are almost insignificant compared with exposures experienced by large populations to elevated natural backgrounds resulting from concrete and stone buildings. Many of these background exposures are subject to simple and inexpensive controls such as requiring a layer of plastic between cellar walls and floors and prohibiting the use of building materials having high levels of phosphates from phosphate mining and other sources. If it is assumed that low levels of exposure to radiation from the normal operation of nuclear reactors constitute a serious public hazard, then these natural background radiations are even more dangerous. To concentrate all radiation risk-mitigation regulation on the nuclear industry would thus be inconsistent (NAS 9).

All nuclear fission reactors produce radioactive wastes. Technologies now exist for encapsulating and entombing these wastes in geologic formations. Site-specific engineering combined with geological knowledge can reduce the long-term public hazards of waste deposits to levels below natural background radiation or other nuclear fuel-cycle activities. But the detailed, site-specific knowledge is now usually inadequate, and efforts to improve the knowledge must therefore be pursued (NAS 5, NRC).

As geologic repositories for nuclear wastes begin to be licensed, the process will be under close public, industrial, and governmental scrutiny because of the hazardous nature of these substances. To devise safer methods of disposal, efforts will be made during the next five years to develop and test models to determine important design features, geologic effects over time, and data deficiencies related to nuclear waste disposal (NRC).

The Oceans

The study of marine ecosystems can lead to the development of improved management tools to conserve and maintain the renewable and fragile living resources of the oceans, specifically fish and marine mammals. Studies that increase our knowledge of such oceanic phenomena as the interaction between the ocean and the atmosphere, coastal upwelling, and changes in ocean current systems will accomplish two purposes: expand the uses to which the oceans can be put and protect them against pollution (NAS 1, USDC, DOT).

SELECTED POLICY CONCERNS

The perception and management of hazards have international implications. Important questions that international institutions may be called upon to address are: the global effects of atmospheric carbon dioxide buildup, acid rain, multinational management of water basins, and exploitation of the seabed; and such vulnerability concerns as the development of nuclear power and the management of radioactive wastes, levels of acceptable environmental risk, and natural catastrophes (NAS 11). International cooperation on these matters is essential because oceanic and atmospheric pollution ignores national boundaries. Action on an international scale will be required to ensure a healthful environment for the citizens of all countries. Efforts to reach international political agreements to minimize these risks will continue (NAS 11, State).

Although hazards, by definition, cannot be beneficial, our increased awareness of them is a positive development. An increase in the general public's understanding of risk assessment is becoming urgent. That is, since the complete elimination of hazards is impossible, informed decisions need to be made that balance the benefits of a particular technology against the risks it poses and the risks of one technology against those of a substitute technology. The decisions can be revised as better scientific information that permits improved assessments of the effects of specific hazards becomes available. Determination of risks and benefits can pose formidable problems, since realistic appraisals must try to assess the long-range economic and social costs of not implementing a particular technology or of imposing stringent regulations upon its implementation, as well as immediate risks associated with less stringent regulations. The need for effective regulatory policies gives urgent priority to the refinement of risk assessment methodologies (NAS 9, EPA, FDA, Seskin and Lave).

Growing public involvement in the assessment of technological impacts has been encouraged by Federal legislation of the 1970s—especially the National Environmental Protection Act and the Freedom of Information Act. The right of citizen representatives to intervene in environmental proceedings has been clarified and extended by recent legislation (Nelkin). However, better studies are needed to assess the relative effectiveness of different modes of public participation, and particularly of the appropriate timing in making public participation maximally beneficial, without unhappy consequences for the broader public interest.

In principle, scientific and technological information about hazards should improve the basis for debates about technologies by clarifying issues of associated benefits and hazards or costs. However, it does not necessarily follow that opponents of a particular action primarily rely on technical information, since individual and social values as well as factual information enter into the determination of acceptable risk. Nevertheless, democratic ideals, as well as the political necessity of seeking a broad consensus for technology policies, imply the need to improve public understanding of risks, costs and benefits and to develop mechanisms to involve those who may be placed at risk as a result of a proposed course of action in arriving at decisions about its implementation (Nelkin, Seskin and Lave).

PARTIAL SYNOPSIS of Volume II Source Materials

This synopsis of the U.S. Government agency reports and the commissioned papers on science, technology and public policy that appear in Volume II is intended as a guide to those source materials. However, a synopsis cannot capture all details of a presentation. For that reason, users of this *Five-Year Outlook* are advised to refer to the original papers whenever possible.

The National Science Foundation prepared this synopsis and is wholly responsible for any explicit or implicit departures from the original papers that may have resulted in the process. However, to the extent that the views expressed in the synopsis of the commissioned papers accurately reflect those expressed in the papers themselves, they are the views of the authors and not of the Director of the National Science Foundation or the United States Government.

The Government View: Statements by Selected U.S. Government Agencies

DEPARTMENT OF AGRICULTURE (USDA)

USDA lists numerous issues in which basic, applied, and developmental research can enhance the economic and environmental value of U.S. agricultural and forest lands:

Natural Resources and Environment

The effects of environmental legislation and regulations on food production must be assessed. More efficient irrigation practices, growth of plants that require less water, and ways to increase water supplies are needed. The effects of weather and climate on plants and livestock must be better understood. Ways must be found to increase crop production on land of lower quality. Economic and legal analyses of government regulations on rural land use are needed. Such variables as farm size, location, and crop raised must be studied so that regulations and policies can be improved. The fate and pathways of plant nutrients and other chemicals in soil and groundwater require investigation.

Energy

Production of onsite energy from agricultural wastes holds promise. Plants are the only renewable raw material that produce some hydrocarbons now obtained from petrochemicals. These plant products presently are not cost effective, but this is changing. The conversion of biomass to energy competes with other uses for which the economics may be more favorable. The use of solar energy in agriculture is now limited, but prospects for dramatic technical breakthroughs that could lower costs appear to justify substantial increases in research.

Agriculture Policy

The structure and organization of U.S. agriculture are changing—for example, the trend to fewer and larger farms. The changes must be analyzed in depth to equip policymakers with a greater understanding of the impacts of Federal programs, market conditions, and technological developments.

Food Industry Structure

Research is needed to determine the effects of government regulations, technology, and competition on the food marketing and distribution sector. There is also a need to identify new alternatives that would ease the access of small and part-time farmers to markets and enhance the opportunities for consumers to obtain high-quality food at reasonable prices. The policy debate over cooperatives and their impact is likely to continue.

World Food and Fiber Forecasting

Aerospace remote sensing has the potential to improve significantly the forecasting of the international supply of food and fiber.

Transportation

More information is needed on how deteriorating railroads, poor roads and bridges, and a variety of government actions are adversely impacting agriculture and rural America.

Crop Productivity

Research opportunities in plant biology include improving the taxonomy of economically important crops, developing plants that can grow efficiently on submarginal land, and learning more about plant physiology and photosynthesis. Nitrogen fixation and DNA research are also important, but they are constrained by a lack of interdisciplinary efforts. Safer pesticides must be developed, as well as improved quarantine procedures and detection methods. Research is needed on the environmental, economic, and social impacts that alternative Federal environmental quality standards, policies, and programs may have on agriculture and rural areas. It is also necessary to establish and maintain ecosystems that optimize food production while providing other benefits. Constraints include the lack of secure research facilities and the slow implementation of integrated pest management activities.

Animal Productivity

Opportunities in animal biology include improving the birth rate of beef cattle and swine and using genetics to develop animals with desirable characteristics. Control and management of the animal microenvironment present such opportunities as protecting livestock from disease and parasites, developing more efficient animal production methods, and finding ways to decrease the impact of pests on productivity. Constraints include removal of certain chemicals formerly used by government agencies, and unanswered questions regarding dietary composition, food safety, and the increase of livestock concentrations.

On-Farm Product Losses

Improved harvesting methods, machinery, storage techniques, and facilities would help minimize on-farm losses. Environment is a key factor in livestock production, and recent research has led to some improvements in this area. The technology needed to alleviate losses is economically unattractive now, although this situation is changing.

Food and Fiber

Environmentally acceptable methods are needed to protect and preserve foods. Food costs can be reduced by developing energy-efficient technologies that reduce handling and improve protection. Food safety must be increased by finding better ways to identify and safely dispose of contaminated products. Natural fibers must be made more competitive with fossil fuel-based products.

Human Nutrition

Steps needed include better understanding of nutritional requirements, improved data on food consumption, and better understanding of how eating habits are formed. Constraints include limits on using humans in research and fragmentation of research activities.

Forest Resources

Research is needed to help resolve the conflict between the growing demand for more goods and services from the Nation's limited forests and rangelands, and increased environmental awareness.

Adequate Forests

The need for forest products will double by the year 2000. Timber research must provide new knowledge about the culture, breeding, and economics of growing trees while preserving other forest values. The lack of appropriate harvesting equipment limits production in many areas. Expanded research is needed to permit using low-quality trees and residues.

Forest Protection

Each year insects, diseases, and wildfires kill an amount of timber equal to one-fifth of the annual harvest; they also impair aesthetic values, recreational opportunities, watersheds, and wildlife habitats. Research is focused on preventive measures and control methods.

- *Soil and water quality.* As the intensity of forest management increases, research is needed on providing adequate supplies of high quality water, protecting the soil, and alleviating pollution.

Habitat for Domestic Species

Past research developed guidelines for tailoring forest and range management practices to the needs of certain wildlife and fish, especially game species; the need now is to develop information that is more widely applicable to nongame species and to a greater variety of habitats.

Recreation Benefits

Research is needed to quantify social and economic benefits from recreation.

Rural and Community Development

More effort is needed to develop comprehensive models that systematically relate development and economic variables as a basis for analyzing, projecting, and forecasting development of rural areas.

New Agricultural Technologies

There is a need for means to anticipate the distributional impacts of any major new technology under consideration, as well as its indirect, delayed, and side impacts.

DEPARTMENT OF COMMERCE (USDC)

USDC's science and technology goals are to promote the efficient production of goods and services, to improve the competitiveness of U.S. industry, and to enhance industry's ability to meet other social goals. To attain these goals, DOC lists 17 areas in which efforts are underway or are needed:

Industrial Innovation

USDC led a domestic policy review that made recommendations on how to stimulate industrial innovation. The review has caused the President to consider programs dealing with procurement, Federal support of research and development, regulations, economic and trade policies, patents, and information.

Government-Industry Cooperation

Government and industry may jointly solve technical problems. One potential program for cooperative development of generic technology in areas of particular need is being studied as a result of recommendations of the Office of Management and Budget.

Alternative Energy Sources

USDC is working to develop energy sources from the Sun, the oceans, and geothermal reserves. Problems in shipping oil and gas from offshore and arctic sites must be solved. Additional environmentally sound petroleum refining and storage facilities are needed on the East Coast.

Materials Shortages

Replacements are needed for scarce materials. Composites can save both materials and energy. Corrosion, fracture, and wear must be reduced, and more resources must be recovered from waste.

Economically Adverse Climate Conditions

USDC lists 15 programs designed to assess the effects of climate, upgrade methods for forecasting, and improve dissemination of data.

Marine Technology

An ocean engineering organization should be set up to manage marine technology efficiently. USDC's National Sea Grant Program is sponsoring research on reducing corrosion in the marine environment, on biological fouling of materials, and in other areas.

Ocean Pollution

USDC research is addressing such problems as oil spills and monitoring of ocean dumping.

Seafood Production

Even though a major share of the world's fisheries lies in U.S. waters, much of the catch is processed abroad because the U.S. fishing industry cannot efficiently catch and process it. Products suitable for large foreign markets must be identified and ways must be found to produce and preserve them. To prevent shortages in the future, supplies of seafood must be increased by agriculture and through research in fish genetics.

Marine Pathogens

Better methods are needed for determining the presence in water of organisms that can spread disease to humans.

Automated Manufacturing

Widespread use of automation in manufacturing can increase production, but lack of capital, resistance by labor, and technological problems are major roadblocks.

Fire Losses

More knowledge of the dynamics of fire can reduce losses and result in better regulations.

Home Communication Systems

Demand may grow for communication systems to supplement telephone and television; optical fiber technologies appear to have potential here.

Toxic Substances

Current procedures for assessing the risks of chemicals are extremely expensive, so it is imperative that assessments be accurate. USDC's National Bureau of Standards helps assure measurement quality through its Standard Reference Data and Standard Reference Materials.

Radiation Hazards

The recent explosive growth of electromagnetic radiation sources causes concern about potential health hazards from nonionizing radiation. Effects of ionizing radiation are a continuing concern. Such radiation is controlled by a number of regulations whose economic impact is significant; thus, the data used in the regulatory process must be accurate.

Scarcity of Radio Spectra

Increased demand for communication systems is resulting in congestion and scarcity in the radio spectrum. New engineering methods of spectrum management, computerized data bases of equipment characteristics, and radio transmission models can help solve this problem. Research may also allow use of infrared and millimeter wave regions.

Rural Communications

Improvements in rural communications would help bring rural social services up to the level of those in urban areas.

Electronic Mail Transmission

Current technologies and infrastructures—including satellites, data communications, and microprocessors—can permit electronic transmission of some mail on a large scale in the near future.

DEPARTMENT OF DEFENSE: ADVANCED RESEARCH PROJECTS AGENCY

The Advanced Research Projects Agency lists 14 "Current and Emerging Problems of National Significance" and then discusses "Opportunities for the Use of New and Emerging Technologies," mentioning constraints on their use where applicable.

Land Combat

Advances in antitank weaponry make development of better armor a necessity. New armor materials will lead to lighter and more mobile combat vehicles. New radar data processing and missile technologies permit targeting with greater accuracy and range.

Aircraft

The urgent need for low-cost high-performance aircraft may be met by the X-wing and forward-swept wing concepts. Better multimode seeker technology will allow missiles to better search for and lock onto targets.

Power Systems

Radical improvements in turbine engines and the development of new materials will allow greater engine efficiency and contribute to fuel conservation. New bearing materials and designs are needed to cope with increased engine efficiency; solid lubricants also will help. Advances in systems for collecting current are needed to develop electrical transmissions, electromagnetic launchers, pulse power sources, and high-energy storage machines.

Antisubmarine Warfare

Improvements are needed in submarine detection systems, as well as in systems to protect friendly submarines from enemy detection. Research is needed in advanced acoustic arrays and multisensor correlation techniques; optical fibers have potential for these applications.

Space Systems

New space-based sensors are needed to warn of enemy missile attacks in any weather. Building larger space structures that are easy to erect and display will require new design concepts and materials (including metal matrix composites). Visible lasers have great potential for space, but coating materials are presently inadequate.

Nuclear Testing Verification

More knowledge is needed about seismic waves, about the Earth's geophysical characteristics and their interaction with explosions, and about methods to measure from space the radioactive emanations from explosions on Earth. Detection methods must be as nonintrusive as possible, yet must be effective from thousands of kilometers away. These difficulties present major roadblocks.

Communications

Packet communications systems provide models for new technology using multimedia information channels. Digital voice transmission systems will allow increased efficiency in encoding and can also be applied to packet communications. In signal processing, new semiconductor designs and other technologies must be developed to cope with ever-increasing amounts of information that must be stored.

Computers

Reductions in the size and weight of computers and increases in their capabilities dictate their increasing use in national defense. Computers under development can store massively greater amounts of information at less than 1 percent of current costs. Constraints on this technology's development include the relative unreliability of existing equipment, the growing cost of implementing software, and the lack of trained personnel.

Training

Training will improve through use of increasingly complex instructional computers. Other advances will be improved videodisc technology and geographically dispersed instructional systems that "bring the schoolhouse to the students." At the same time, expert systems can replace personnel in performing many monitoring and repair functions.

Cybernetics

Human neural processes must be better understood, including the effects of stress on decisionmaking. By 1985, computerized "warning systems" will be available that can analyze economic, political, and military variables to provide alert lists and country-situation profiles. New computer technologies will focus on commander-oriented systems for quick personal use. However, the importance of human factors in the design of sophisticated new weapons systems is not fully appreciated.

Defense Costs

The new theories of wear, new methods for detecting it, and new surface treatments being developed may lower the cost of national defense over the next five years. New coating technologies that provide better resistance to corrosion and rust will conserve equipment and lower costs. The application of new technology to manufacturing processes allows greater uniformity and control; however, the importance of this technology frequently is overlooked. In addition, conservation of materials is not often considered as a way to lower defense costs. Reducing dependence on critical foreign materials is vital to national security.

DEPARTMENT OF DEFENSE: AIR FORCE

In addition to its own resources, the Air Force uses industry and the universities to carry out research and development. To improve its planning efforts, the Air Force has developed a major initiative, Project Vanguard. Basic research is underway in a number of near-term projects that deal with advanced technologies such as charged particle beams, long-life rechargeable batteries, microwave tubes, and toxicological hazards.

Research and development resources are concentrated in seven near-term technologies:

Propulsion

Past research on the turbine engine has concentrated on improving performance, but the thrust now is to improve stress durability. Work is also continuing on spacecraft power rocket propulsion, ballistic missiles, and fuels.

Materials

New materials for structural applications, seals and sealants, and long-life gas turbine engine components are currently being researched.

Flight Vehicles

Improved structural materials, designs, and components are being developed. Major considerations will be: improvement in aircraft performance, reliability, and survivability; reduction in costs; and energy conversion.

Weaponry

Conventional munitions research will concentrate on antiarmor technology, including a new short-range air-to-air missile. Development of laser weapons will continue, and new and emerging technologies will be studied to determine if they can be used in weaponry.

Electronics

Advances here will dramatically improve aircraft performance. High-speed circuit technology is improving under a triservice research program.

Environment-Geophysics

Research continues to design equipment that can function efficiently under all environmental conditions, while meeting environmental regulatory standards. Data from the Spacecraft Charging At High Altitude (SCATHA) satellite and the Optical Atmospheric Quantities in Europe (OPAQUE) program will be reduced and analyzed.

People

Better measures of recruit aptitude and attitude, along with computer-based instructional methods, are being developed. Biomedical research in Fiscal Year 1980 will emphasize the chronic effects of low-level radiofrequency radiation and predictive toxicology. The Health Evaluation and Risk Tabulation (HEART) program will help reduce heart disease occurrence in personnel.

Long-Term Technology Issues

These include decisions concerning what percentage of the Air Force budget should be allocated for R&D, whether spaced-based systems can survive well enough to justify our increasing reliance on them, and whether we can exploit technological opportunities quickly enough to use them.

DEPARTMENT OF DEFENSE: ARMY

The Army's five-year science and technology goal is to enhance its ground combat capability. Meeting the goal requires solving a number of key problems.

Armor and Counterarmor Capability

New and better materials must be fabricated for use as armor, and armor-penetrating technology must be improved.

Command, Control, Communica · ·, and Intelligence

New equipment is needed to increase the ability to handle and process large volumes of data and communications under combat conditions. VHSI (very high speed integrated) circuits may overcome significant shortcomings of current military computer systems by reducing the size, weight, power consumption, and failure rate of existing systems, thereby realizing significant savings in both initial and life-cycle costs. Radio equipment must be improved to neutralize more easily deliberate jamming and relieve crowded spectra. Low-cost optical fiber communications offer some advantages over present wire and cable systems, and optical fiber purification techniques can overcome vulnerabilities to nuclear radiation.

Ability to Conduct Combat Operations under Adverse Conditions

One of the most promising opportunities for operating when visibility is poor lies in exploiting the 100 to 1,000 GHz portion of the electromagnetic spectrum.

Battlefield Mobility and Firepower

New fuels such as gasohol or methane, alternatives to the internal combustion engine, lightweight materials, and smaller and lighter rechargeable batteries are urgently needed. Use of realistic "engagement simulation" techniques in combat training has proved more successful than earlier techniques.

Health and Survival of the Combat Force

Research on military disease hazards is advancing dramatically, and the trend is likely to continue. Progress in immunobiology is most spectacular, opening new avenues for rapidly identifying microorganisms, understanding disease mechanisms, and developing preventive measures. Research on DNA, on accelerating immune responses, and on integrated controls of pests is continuing. Research on blood will be multifaceted. Research also will continue on munitions effects, anesthetics, better animal models, protection against occupational exposure to hazardous substances, better protective clothing, and psychological stresses. Military dentistry must also be improved.

Fire- and Flame-Resistant Fabrics

Research on the use of intumescence in textiles may significantly decrease the flammability of future fabrics.

Structures

Recent dam failures make necessary the development of continuous monitoring techniques that are cost effective, precise, and reliable.

DEPARTMENT OF DEFENSE: NAVY

The Navy's science and technology objectives fall within six categories:

Materials and Structures

Corrosion is a major problem aggravated by dependence on scarce foreign materials to combat it. Efforts to deal with corrosion include research on such new anticorrosion techniques as surface modification through ion implantation. Predictive models must be developed to understand the problems of gradual degradation of ship capability.

Information from Computers

Humans are limited in their ability to quickly assimilate much data from numerous sources. Research is therefore needed on all aspects of computer-aided decisionmaking, including logic. Studies are also needed on the interaction of all computer components.

Military Science

The ability to "see" submarines and targets beyond the horizon must be perfected. Research is needed to develop fast turn-on highpower devices and passive range-determining techniques, and to learn more about frequency and phase codes. Constraints include the lack of priority, workable ideas, trained personnel, and money.

Health

A vaccine for malaria is a possibility. Research is continuing on the effect of the electromagnetic environment on humans. Genetic engineering can create biological warfare agents, but can also provide useful drugs. The causes of diseases with long latency periods must be studied. Prostaglandin B1 can help alleviate the lack of oxygen to wounded parts of the body, but more research on that subject is necessary. Human response to motion, acceleration, and impact must be studied. Due to increasing nationwide concern about protecting human and animal subjects in research, suitable alternative models must be developed.

Environment

Information on the ocean and arctic environments is needed and can be gained by use of satellite sensors, onsite measurements, and computer modeling. Information is required on propagation, including microwaves, and solar and plasma radiation. A substitute for creosote is needed if the Environmental Protection Agency bans its use.

Manpower

Improving work-force effectiveness through better selective and testing techniques is a major need. A declining reservoir of young people is leading to recruitment and retention problems. A single plan to deal with manpower problems must be developed.

DEPARTMENT OF ENERGY (DOE)

DOE's near-term science and technology outlook is directed broadly toward developing solar, nuclear fission, and fusion energy resources to replace dwindling supplies of petroleum, and toward transforming the more abundant fuels—coal, for example—into alternate forms. Conservation of supplies is also a major DOE thrust. The major categories of research are:

Solar Energy

For solar energy to compete with conventional energy sources, it must be made more cost effective. Research is necessary in many areas, including materials science, basic physical and chemical phenomena, systems for use in oceans and space, and solar energy storage.

Geothermal Energy

Research is needed in a number of areas, including novel techniques for characterizing geothermal resources, direct heat applications of geothermal fluids, and development of new drilling technology. Three types of geothermal energy have the most promise: vapor- and liquid-dominated hydrothermal energy, geopressurized hydrothermal energy, and hot dry rock.

Fossil Energy

Research is needed to make present extraction and processing techniques more efficient. Modern scientific tools—including nuclear magnetic resonance, chromatography, microwaves, and lasers—are revealing the structure of fossil fuels and the fundamental mechanisms involved in their processing. This knowledge provides the basis for innovative ideas for new or improved technologies in such areas as conversion of coal to clean fuels, direct combustion of coal, enhanced oil and gas recovery, use of oil shale, coal liquefaction and gasification technology, and electrical power generation.

Fission Energy

First, DOE will refine the light water reactor as a major electricity source by dealing with siting and waste management problems. In this regard, low enriched uranium oxide fuels, chemical cleaning techniques to reduce radiation fields, and safety technology must be developed. Second, such alternative reactor concepts as the Liquid Metal Fast Breeder, the water-cooled breeder, and the gas-cooled fast breeder will be studied. DOE's third fission objective is to develop an effective waste management policy. Public participation will be a major factor in shaping this policy. Research is needed on conversion of wastes into a form safe for long-term geologic storage, and on development of handling, storage, and monitoring techniques.

Fusion

This technology will not be commercially available until the next century. Two approaches are being explored—magnetic confinement and inertial confinement. Near-term objectives of fusion research include demonstration of its feasibility, establishment of a sound engineering development base, and reduction of experimental research costs. Technical issues needing investigation are plasma behavior, scaling laws, prototype and technology development, and materials behavior. Important environmental issues include control of radioactivity, safety analysis and engineering, and hazards to ecology and human health.

Environment

DOE conducts extensive research on safety and on how all energy technologies affect health and the environment. Four major research areas are under investigation: (1) Pollution studies include determining the chemical and physical mechanisms of pollutant transformation in the atmosphere, developing models for predicting biological effects, and developing better measurement technology. (2) Environmental studies aim to identify pathways and rates of transfer of energy-related pollutants, to determine their biological effects, and to eliminate pollutant pathways. (3) Health studies seek to identify the biologically active forms of hazardous agents, develop useful and sensitive indicators for detection of biological damage, and determine the effects of pollutants on people. (4) Carbon dioxide studies aim to predict future atmospheric concentrations and discover ways to reduce their impact.

Basic Energy Sciences and High-Energy and Nuclear Physics Programs

The Basic Energy Sciences program will expand significantly in scope in 1980, particularly in solar biomass technology. Research is also needed in the geosciences and on safe immobilization of nuclear wastes. DOE is the principal agency for high-energy and nuclear physics research, subjects of great national importance. DOE will strive to maintain this Nation's world leadership in the field.

DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE: ALCOHOL, DRUG ABUSE, AND MENTAL HEALTH ADMINISTRATION

National Institute on Alcohol Abuse and Alcoholism (NIAAA)

The National Institute on Alcohol Abuse and Alcoholism (NIAAA) will conduct research in a number of areas during the next five years. Efforts to uncover possible genetic, familial, or psychosocial factors that may predispose a person to alcoholism or other alcohol-related disorders must be stepped up. Studies of pathogenesis must focus on the mechanisms by which alcohol affects metabolism, immunologic responses, endocrine functions, neurophysiological and psychiatric processes, and on alcohol's relation to such major disorders as cancer. Diagnostic techniques for the early identification of alcohol problems must be developed, including laboratory and functional objective tests.

Studies will seek to develop more sophisticated and useful methodologies for assessing both new and existing treatment techniques. Research is needed to identify basic principles of learning and motivation in alcohol-related problems (for example, accidents and violence) and to explore how economic and regulatory techniques or familial and peer relationships might be used as mechanisms for prevention programs. Alcohol-related fetal disorders are in need of study, as is the value of alcoholic beverage control laws as a preventive technique. High-risk populations and drinking practices must be identified; in addition, information networks are required so that new research can be passed on quickly to clinicians.

National Institute on Drug Abuse (NIDA)

The National Institute on Drug Abuse (NIDA) research will be directed to many areas. The use of LAAM, naltrexone, and buprenorphine to treat heroin addiction shows great promise. Research will also continue on the psychological dependence of users and on the psychology of treaters. The Treatment Outcome Prospective Study is an effort to understand the natural history of persons entering Federal treatment programs. Studies of the mechanisms underlying pain relief continue, as do those of factors that predispose persons to cigarette smoking. Research is expanding on the potential role of polypeptides as the brain's regulators of pain and pleasure and on their role in mental functions. Knowledge about neural pathways and the role of chemical neurotransmitters is growing, which should lead to advances in general mental health.

Physical predisposition to drug abuse and its neuroscientific basis must be studied. Drug abuse and other disorders of self-control (including alcohol and tobacco use and, possibly, gambling) might be attacked collectively if self-control mechanisms were better understood. Research is underway to determine the factors involved in the initiation of drug abuse behavior patterns and to increase our understanding of drug abuse careers. Studies are planned on the genetic, immunological, and developmental effects of marihuana on 11- to 15-year-old users, who may be harmed more than young adults. Prediction studies can probably formulate equations to indicate which children are most likely to abuse drugs. Studies of family, socialization, and group factors will continue, to determine their effects on drug abuse in adolescents. Research is also underway in a number of other areas.

National Institute of Mental Health (NIMH)

The National Institute of Mental Health (NIMH) will be conducting research in childhood and adolescent disorders; the study of psychopathology in these persons has not kept pace with studies of adults' problems. Research on disorders of aging must be stepped up as our population grows older. In epidemiology, better data are needed on the extent of mental disorders, where they are treated, and at what cost. Two main areas of treatment research warrant attention: the efficacy of psychosocial treatments for mental health problems, and drug therapy. Also of importance in NIMH's efforts are basic research (including genetics, neurotransmitters, and brain chemistry) and clinical research on schizophrenia, diagnostic procedures, and depression. In prevention, the importance of specific risk factors must be determined, and public attitudes toward mentally ill persons must be improved.

DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE: FOOD AND DRUG ADMINISTRATION (FDA)

A review of FDA's anticipated science and technology needs over the next five years identified seven broad areas of research:

Bioassay Methodology

Crucial problems are the shortage of animals for in vivo testing of potentially toxic substances and the consequent need for these tests to be supplemented or replaced by rapid, in vitro tests. In vitro testing to determine structure-activity relationships can allow prescreening of candidate substances in need of in vivo study. Current emphasis is on rapid in vitro screening for carcinogenicity. The placebo effect must also be studied.

Toxicology

As analytical methods become more sophisticated, new tests, screening programs, regulations, and monitoring programs are needed. New toxicological endpoints must be assessed, due to advances in knowledge of immunotoxicity, neurotoxicity, and behavioral toxicity. Knowledge is also needed on new routes of exposure, particularly inhalation and absorption by the skin. A linear dose response in toxicity bioassays is not always encountered, so the extrapolation of high-dose experimental effects in animals to low-dose effects in humans will be a controversial topic. Methods to identify the effects of cocarcinogens and promoters are sorely needed. Finally, more knowledge is needed on the metabolism of chemical agents and how their biological effects are modified.

New Substances

Among the numerous new products regulated by FDA that will enter the market in coming years will be better vaccines against hepatitis, influenza, and other viral and bacterial strains. Polypeptide hormones (for example, human insulin) and biologically active polypeptides (some for use as nonaddictive analgesics) will undoubtedly be available. All of these products, along with the broad-spectrum antiviral interferon, are candidates for production via DNA cloning techniques. The resulting products are expected to create novel problems of production and purification.

Analytical Chemistry

Some toxic and carcinogenic agents (for example, dioxins) produce effects at the parts-per-billion or trillion level. Detection of such agents taxes the state of the art of analytical technology, and more sensitive methodology is needed. Rapid, inexpensive, automated, multiresidue assays are needed for animal drug and pesticide residues, industrial contaminants, and other toxins—some as yet not isolated. The purity of regulated products (antibiotics, food colors, commercial chemicals) will be improved through better analytical techniques to discover impurities and contaminants. New analytical technologies (computerized mass spectrometry, Fourier transform infrared spectroscopy, and laser Raman spectroscopy) are being increasingly applied to regulatory problems. Such rapid progress also creates regulatory problems.

Radiation Safety

Efforts will be made to reduce unnecessary clinical exposure to x-rays and other ionizing radiation sources.

Assessing the health effects of such nonionizing radiation as ultrasound and microwaves is likely to be intensified because the potential hazards are poorly understood.

Risk-Benefit Analysis

Risk analysis raises many technical, practical, and ethical problems; the prospect that current regulations may be expanded to include benefits raises additional issues. A study is needed on the effectiveness of previous risk-benefit analyses. Baseline, consumption, and incidence surveys are necessary. Current total diet studies for pesticides, industrial contaminants, and nutrients can be anticipated.

Other Problems

These include the need for improved methods to determine bioequivalence of drug substances; knowledge of the relation between nutrition and disease; biocompatibility of medical devices; new diagnostic products; control technology; and coordinated planning of research and emergency responses by FDA and the government in general.

DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE: NATIONAL INSTITUTE OF EDUCATION (NIE)

Recent progress in three areas of science and technology—when developed and implemented—will have important effects on education:

Cognitive Science

The new understanding of human intellectual processes growing out of cognitive science permits better designed instruction and testing, which can be more closely fitted to cultural background. For example, knowing the basic processes by which people understand language (instead of merely measuring their comprehension of it) can allow a teacher to determine the processes in which a student is weak, thus facilitating remedial instruction. Advances in this field are also permitting development of computer programming that can simulate human cognitive processes. NIE's Center for the Study of Reading is giving major attention to the role of background knowledge in reading comprehension, to prior language experiences, and to reading strategies and tactics. A 1978 NIE conference on testing research recommended research in such areas as the use of tests as teaching instruments, multiple forms of assessment of student learning, and the effect of cultural and linguistic factors in testing. Such research will soon be underway. Advances in sociolinguistics and videodisc technology are allowing a greater understanding of how students interact and learn in the classroom.

Information-Handling Technology

Devices currently on—or nearly on—the market include computers and calculators, videodisc systems capable of storing 10 billion bits of information, and other such technology as TV games and word processing devices. Information-handling technology will keep students actively learning for a longer time and will identify individual student needs more efficiently. NIE favors Federal funding of research on computer-based education programs. This research should focus on both the technology and ways to manage it effectively. NSF and NIE are cooperating on research and development using this technology, and NIE is doing some research on its own. More is needed, however. Information handling can be applied to drill and practice, new test design, and other educational problems. It can supplement regular classroom instruction as well.

Organizational Science

The bureaucratic structure of educational organizations has come under increasing criticism. This problem has been aggravated by changes in demographics that have occurred too rapidly for educational institutions to cope with them. Attempts have been made to apply modern management and information sciences to educational organizations. However, two problems have interfered: more information is needed about the details of teaching activities and their susceptibility to change, and educational organizations' goals and technologies are less defined and understood than in other types of organizations. Additional research on educational organizations is needed.

Other problems fundamental to bureaucracies include overemphasis on procedures and hierarchy, too much specialization, and too much dependence on rational planning, even in the face of uncertainty and conflicting information. These are particularly noticeable in educational organizations. Research on these problems is currently being carried out by NIE and will be used in the design of new educational support programs.

DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE: NATIONAL INSTITUTES OF HEALTH (NIH)

A National Conference on Health Research Principles was convened in 1978 to map out a strategy for biomedical research in the next five years. Among the critical national issues that will confront NIH are the following:

Sustaining Basic Research

The national conference stressed the need for a strong commitment to basic research, which in the past has contributed immensely to improving human health and well-being. Progress is being made in genetics, immunology, virology, cell biology, and the neurosciences; however, the science bases needed to combat cancer, heart disease, and other health problems are complex and imperfectly understood. Difficult tradeoffs must be made between funding long-term and short-term research.

Recombinant DNA Research

This research has great potential in a number of applications, but questions of health and safety remain. NIH guidelines on recombinant DNA, issued in January 1979, will go a long way toward protecting public health and the environment from possible risks. NIH will closely monitor application of these guidelines for several years to assess their effectiveness.

Major National Health Problems

Cancer remains a major problem, but progress is being made toward prevention through the recognition of environmental factors as major causes. Public education efforts to help high-risk populations will begin in 1980. Progress in combating leukemias, lymphomas, and certain childhood cancers has also been dramatic. Efforts to combat heart and lung diseases will continue apace in the 1980s, and new instruments allow noninvasive early detection. Studies will be conducted on aspirin as a treatment for coronary artery disease and hypertension. The National High Blood Pressure Education Program will be developed further, and the Food for Health Program will be used as a model for new education programs on nutrition. Other important health problems being addressed include arthritis and diabetes, digestive and infectious diseases, and aging.

Environmental Toxicology and Nutrition Research

The National Toxicology Program, begun in 1978, is designed to assess and coordinate all toxicology research in various HEW agencies. It will be implemented by the National Institute of Environmental Health Sciences. The National Library of Medicine's TOXLINE and CHEMLINE computerized information systems support the program. Nutrition research at NIH is coordinated through the Nutrition Coordinating Committee. Current research efforts are aimed at discovering the effects of diet, as both a causative and preventive factor, on many chronic diseases.

Technology Transfer

NIH established an Office for Medical Applications of Research (OMAR) in 1977 to coordinate technology assessment activities. The assessment process used is "consensus development," which means agreement by a majority of experts on the efficacy of a new technology. The 1977 OMAR breast cancer screening conference resulted in a number of improvements in breast cancer screening; 25 similar conferences are planned for 1979. Information services will soon include a computer information system being developed by the National Library of Medicine. Other areas with promise include telephone information transfer and videodisc technologies.

Management of Science Resources

A major management problem is the need to renovate, rehabilitate, or replace research facilities and to replace obsolete equipment. The problem can be mitigated by sharing equipment, designing buildings with greater ingenuity, and considering energy and maintenance costs. A second problem is the decline in research opportunities for young scientists. This problem can be approached by closer liaison between NIH and academia, a relationship that is not ideal at present. Modification of the tenure system is being regarded anew by academic institutions. Directing Ph.D. candidates to fields where the demand is high can also help. Lack of funding in all the above areas is a major constraint. Efforts to stabilize and maintain the science base funding are essential.

DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT (HUD)

The rapidly changing social, economic, and political conditions under which HUD operates make firm projections of extended research plans almost impossible. However, the Department has identified nine areas that indicate the current scope and trend of its research objectives:

Urban Economic Development, Public Finance, and Tax Policy

Research seeks to help state and local governments deal with problems of development, private employment opportunities, revenue, and finance.

Housing Needs and Services for Special Users

Research aims to identify the impediments to independent living for people with special requirements (the elderly, the handicapped, and rural residents), to develop information about the need for delivering housing and special services, and to design and implement better delivery techniques.

Neighborhood Reinvestment and Revitalization

Research is needed to resolve issues related to the stability and conservation of older inner city neighborhoods.

Economic and Racial Freedom of Choice in Housing

Research on freedom of choice in housing for minorities will be extended to examine the behavior of minority home-seekers and further examine the behavior of estate and rental agents. The fair housing evaluation will be continued and expanded to Hispanics. Discrimination against women in mortgage credit markets will be studied, and a program developed to help women and minorities gain greater access to high-level government positions.

Alternative Housing Finance Mechanisms

A special task force will be created to examine housing costs. Soaring costs lead to increased demand for subsidies, which conflict with the need to balance the Federal budget. Innovations to increase the competition among financial institutions have evolved, and their effectiveness must be reviewed. In addition, the impact of the Financial Institutions Act must be examined, ways must be found to combat discrimination among lenders, and the economic feasibility of solar energy in single-family dwellings needs to be determined.

Housing Assistance for Lower Income Families

The effectiveness of the Section 8 Housing Assistance Program will continue to be evaluated, and the large amount of information gathered by the Experimental Housing Allowance program will be analyzed to determine the impacts of alternative approaches to housing assistance.

Management of Assisted Housing

This research is designed to identify the nature and causes of problems in assisted housing and devise means to alleviate the problems and improve management practices. While earlier research involved testing specific remedies for individual housing management problems, current research is aimed at devising broader strategies for improving assisted housing operation overall.

Evaluation of HUD's Operating Programs

Among the operating programs to be evaluated are: those funded by the Commmunity Development Block Grants, two urban simulation models, Section 701 activities (to analyze various aspects of the local planning process), and HUD's environmental protection policies.

Improving HUD's Data Base and Information Sources

Housing data collected by the Bureau of Census will be analyzed to answer policy questions about housing stock, changes in housing and neighborhood quality, housing cost burdens, and household migration by race and income. Tax policies as they affect housing production and maintenance will be analyzed. Research will continue on general housing economic issues and development of new techniques for analyzing housing market behavior. Availability of 1980 census data will offer new opportunities.

DEPARTMENT OF INTERIOR: BUREAU OF MINES

During the next five years, the Bureau of Mines will conduct research and development in three major areas:

Environmental Impact

Developing technology to allow better compliance with government environmental regulations and performance standards will have priority. The Bureau's program encompasses the entire mineral cycle, from initial exploration through active mining and processing, and on to final restoration of the land and reclamation of the processed materials. These programs include:

- Control technology (operational) where ways are being developed to reduce or eliminate the undesirable environmental conflicts, impacts, and occupational hazards associated with mining and mineral processing. Major problems under study include alternative processes, noise, vibration and fugitive dust, subsidence, waste management, and water management.

- Environmental assessment research is underway in a number of areas, such as the impact of mining on surface and groundwater systems, soil conservation, more efficient methods for gathering baseline data required by recent legislation, and improved planning and design of mines.

- Control technology (postoperational) where improved technology is being developed to facilitate the restoration of lands disturbed by mining and milling for beneficial, long-term use. Involved in this effort are the study of land-use alternatives, safe mine closure methods, reclamation technology, and surface stabilization techniques.

Health and Safety

Research in this area consists of three elements: comprehensive enforcement of existing and new mandatory standards, expanded and upgraded education and training activities, and technical support.

- *Safety research* deals with prevention of fires and explosions, and addresses such problems as ignition, detection, and control in coal mines. Research on the geology of coal beds to allow prediction of methane content will facilitate development of ventilation and control measures. Probing radar has promise for predicting failure of the ground, and development will continue on safer mining designs to allow industry to meet increasingly stringent safety standards. Increased emphasis will be placed on training, accompanied by research on human error and behavioral techniques. Research continues on safer hauling equipment, better emergency life-support systems, and new rescue technology.

- *Health-related research* helps develop devices to monitor dust levels in mines and improve dust collection technology. Radiation in uranium mines is a big problem, and better radiation measuring and protection techniques are appearing. Research continues on noise abatement and instrumentation, and on management of toxic emissions from underground diesel engines.

Mineral Resources Technology

Research to reduce our requirements for critical and strategic minerals from foreign sources will be conducted, resulting in increased conservation, substitution, and recovery of minerals and metals from domestic resources.

- Mineral science and technology research to expand the minerals science and technology base is progressing both through the development of data for use in devising energy-efficient mineral processing sequences, and through fundamental studies on the physical chemistry of mineral-reagent interactions in sulfide flotation. Many extraction technologies are under development that will increase efficiency across the full minerals cycle.

- In an attempt to conserve resources, research is underway to maximize resource recovery. Work is progressing on the recovery of cobalt, nickel, and copper from Missouri lead ores and on the hydrometallurgical recovery of alumina from dawsonite, as a byproduct of oil shale processing. Technologies are being developed to reclaim valuable constituents from wastes and for sorting aluminum from steel contained in scrap.

- Research is progressing on the development of substitutes for critical and strategic minerals by using domestically available minerals. A process research unit is in operation to recover tungsten from Searles Lake brine; the recovery of vanadium from low-grade western resources is being demonstrated; and clay is being evaluated as a replacement for bentonite as a binder for iron oxide pellets.

DEPARTMENT OF INTERIOR: GEOLOGICAL SURVEY

The Geological Survey's science and technology goals for the next five years can be placed in two categories—basic and applied research, and application of existing technologies. Issues in the first category are:

Energy Availability

Research is needed in petroleum geology, secondary oil recovery techniques, assessment of outer continental shelf oil and gas resources, and other areas.

Increased Food and Fiber Production

To increase agricultural productivity, research is needed on the effects of irrigation in the East and of abandoning irrigation in the West. Regional distribution of trace elements in the soil should also be studied.

Management of Wastes

Efforts to cope with wastes include determining nonpoint sources and their impact on surface and ground water, movement of contaminants in the environment, and management of nuclear wastes.

Minerals Availability

A data base that will help formulate public policy will result from research in the following areas: evaluation and identification of mineral deposits; development of new geological, geophysical, and geochemical exploration techniques; and surveys of marine mineral resources.

Prediction of Geologic Hazards

Techniques must be developed to predict earthquakes, volcanic eruptions, landslides, and other natural hazards. Safe siting of nuclear power plants must be ensured, and geologic hazards to mining operations and reclamation must be assessed.

Environmentally Sound Extraction Policies

Research is needed in the environmental problems of energy production, the development of noninvasive geophysical characterization techniques, the impact of surface mining on water resources, and the determination of long-term effects of burning fossil fuels. Research topics resulting from the interaction of these areas include: a useful national assessment of our mineral and water resources; determination of the amount of groundwater available nationwide; and more knowledge of past climatic conditions.

Issues in the second category, application of existing technologies, are:

Computer Processing

Application of computer technology to nongraphic, digital storage, handling, and manipulation of spatial data will continue to grow. The data are needed to support research, to assist water managers and land-use planners, and to prepare environmental impact analyses.

Digital Cartographic Data Base

Through 1985, the Survey will develop this data base for coastal areas, coal and public lands, and other areas; the resulting information will be offered in usable form to Federal and state agencies.

Remote Sensing

Satellites can provide valuable data on the Earth's resources. Meteorological satellites are useful in mapping weather patterns, and Landsat has proven the value of multispectral, synoptic, and repetitive views of the Earth. Improvements will make such technology cheaper and more efficient, so use will continue to grow.

Airborne Profiling

This system, which permits rapid collection of three-coordinate position information, will provide data for mapping, surface subsidence, strip mine monitoring, and other applications when it begins operating in the early 1980s.

DEPARTMENT OF STATE

The State Department's outlook identifies problems and opportunities relating to science and technology in foreign affairs during the next five years. Science and technology provide tools that help in the solution of global problems. They also create foreign policy problems while, at the same time, providing bases for international cooperation.

In international peace and security matters, State sees these areas of major concern:

Weapons

Many nations, rich and poor, are interested in acquiring conventional weapons, a trend that can alter military balances.

Nuclear Technology

It becomes increasingly important to strengthen safeguards as nuclear technology spreads. Improved technical controls may be particularly important in coping with terrorists.

World Development

Efforts will have to be focused on using science and technology to further development in the Third World. More cooperation—financial as well as scientific—among developed nations will be required for expensive international research involving energy resources, ocean margin drilling, and climate.

China

The role that China will assume in the world will be very much a function of its development in military and other technologies.

Treaties and International Law

Two major areas of developing law in which technical factors are particularly relevant are the sea and space.

In natural resources and environment, a large number of current and emerging problems are identified:

Energy

Fossil fuel resources are being depleted at an alarming rate, thus threatening supplies not only of energy but also of such materials as pharmaceuticals and fertilizers. With renewable sources of energy unlikely to be developed for two decades, the use of coal and nuclear reactors will grow, raising issues of environmental quality, human safety, and (in the case of breeder reactors) proliferation. Developing nations could present special problems if they stress immediate costs over long-term environmental concerns.

Forest Reserves

The developing countries may suffer grave consequences if they too quickly deplete their forests, leading to erosion and loss of fertile land. The loss of forests and the burning of wood can also create global atmospheric problems.

Deserts

Desertification is a growing concern. Reclamation—which would benefit many developing countries—is expensive. Some experiments have been successful.

Water Resources

Improved technologies for locating and exploiting underground water sources and for desalting of sea water can be expected. More fresh water is a key consideration, especially to developing countries.

Weather and Climate

International cooperation will permit gathering more weather information on a global scale. Progress in weather modification is slow—research is difficult, and benefits and risks must be balanced. Interest is intensifying in the long-term trends of climate and their implications for the economic health of nations and regions.

Living Resources in the Oceans

All ocean-related activities must be managed so as to optimize their benefits to mankind while, at the same time, conserving the marine environment and its living resources. Our increasing ability to understand the ocean and monitor its changes will help achieve that goal.

Other Ocean Resources

The minerals and fossil fuels of the oceans are another valuable resource. Deep sea mining is nearing reality, making it essential that a legal framework for it be established. Exploitation of the ocean beyond national jurisdictions has not been resolved. Any resolution must accommodate the traditional freedom of the high seas.

Mineral Resources

Global interdependence in the supply of many mineral resources has become a fact of life in the last half of this century. Stockpiling is of limited value. Over the next five years, we may become increasingly vulnerable to developing countries, which seek to gain political influence through control of their natural resources. The effect will probably be to stimulate alternative supplies and development of substitute materials. New techniques of resource discovery (satellite remote sensing) and of extraction, processing, and even transportation may help to develop new supplies. Extraction and processing in developing nations will require technology and capital. Environmental damage and social stresses are probable side effects.

Pollution

In general, the international aspects of pollution are growing in importance, since such phenomena as acid rain, ozone depletion, and even eutrophication (in regions like Europe) recognize no political boundaries.

Waste Management

At the present state of technology, not all wastes are recyclable and so require safe disposal. Radioactive wastes are a controversial and challenging disposal problem.

Natural Hazards

Science and technology hold promise for eventually providing a reasonable capability to anticipate natural disasters, plan settlements to minimize vulnerability, and alleviate consequences.

Food Supplies

A continuing effort is needed to provide adequate food supplies. Not only are technical advances required, but so are innovative organizational and administrative approaches, particularly in delivering fertilizers and water to farmers and distributing and storing their products.

Basic Research

Basic research should continue to provide opportunities for international cooperation.

In international commerce and the economy, the following problem areas are identified:

Economic Development

Technology is crucial in economic development. The lack of an appropriate infrastructure in most of the developing countries thwarts attempts to transfer technology.

Telecommunications

Rapid advances are underway in telecommunications, perhaps leading to overcrowding of radio frequency spectra and satellite orbit space. Several countries expect to be operating their own domestic satellite television broadcasting systems, and at least one regional system may soon be in place.

Free Flow of Information

Despite recent international affirmations of the principle of free flow of information and ideas, some countries continue to urge controls. A number of countries have adopted schemes to regulate the flow of data that might affect privacy or other rights of citizens. The information gap between developed and developing countries is growing.

Commerce

Agricultural products will continue to be our largest export, but trade in technology products and technology transfer will probably increase.

In human resources and welfare the problems are:

Population

Underlying many of the problems already identified are population increases. The pressures in the next five years will be to develop creative and incisive approaches to family planning and improved living standards.

Medicine and Health

Living standards will be raised by better health care. Health care is an area where developed countries can bring the benefits of science and technology to developing countries with minimal—but in some cases, significant—impact on their cultural and social integrity. Consequently, this is a prime area for expansion of international activities.

International meetings and agreements will continue to provide opportunities to further U.S. foreign affairs. An outstanding example of international cooperation is the Deep-Sea Drilling Project, which has revolutionized the earth sciences and led to general acceptance of plate tectonics. A major new program has been proposed for the 1980s, primarily to investigate the outer continental margins of the oceans.

DEPARTMENT OF TRANSPORTATION (DOT)

DOT's research and development efforts will be directed toward transportation problems in the following areas:

Marine

As the number of offshore resource platforms grows, it will become more difficult to reach such goals as reducing the number of ship collisions and other mishaps, quickly repairing damage done by oil and chemical spills, enforcing laws and treaties affecting U.S. waters, and minimizing the danger of carrying hazardous substances. Advanced navigation systems, use of monitoring satellites, improved training, and techniques for cleaning up oil spills are being developed to deal with these problems.

Aviation

Air traffic control and navigation will be upgraded by making use of integrated circuits, minicomputers, high-speed microprocessors, and solid-state radiofrequency technology. The upgrading program will be massive in scope, but this is necessary to meet the air traffic demands of the next two decades.

Roads and Highways

Use of waste and new types of materials for highway construction and repair must increase; sulfur as a construction material is particularly promising. The U.S. highway system is wearing out and is in need of rehabilitation. Protecting the large new investments will require determining the appropriate loading level of large vehicles. Deliberate overloading is another problem.

Highway Safety and Other Needs

New approaches are needed to relieve urban congestion and provide a safer driving environment. Research topics in line with these objectives include: improved methods to expedite movement of public transportation vehicles; special routing and scheduling techniques for cargo vehicles; and simulation techniques to help local officials devise effective traffic strategies. Problems of highway safety, energy, and maintenance costs require long-range approaches. Automation of highways and vehicles would be cost effective and would improve safety in some applications, but a massive change in public attitudes would be essential. Use of automated systems such as microprocessors in vehicles could solve many mechanical and safety problems. Vehicle fuel economy and safety features are continually being upgraded; DOT's Integrated Vehicle Systems Program will evaluate advanced technology in these areas. In general, DOT—in partnership with industry—wants to "reinvent the automobile," so that "socially responsible" vehicles will one day be the norm. Diesel cars reduce fuel consumption, but their exhaust products may pose health hazards.

Rail

Research is needed on how to transport radioactive and other hazardous materials safely. DOT also has three ongoing programs that have as their goal the movement of more long-haul trailer traffic by rail instead of by highway, thus improving fuel efficiency and reducing highway congestion and pollution.

Urban

Paratransit systems, especially for the handicapped and elderly, must be developed for use where fixed routes are uneconomical. The Downtown People Mover program is a national demonstration of how fully automated systems can improve traffic circulation and distribution in center cities. Finally, DOT, with the Department of Energy, is working to develop more energy-efficient and environmentally acceptable mass transit vehicles.

Pipelines

Efforts should be made to prevent failures of operating pipelines and to minimize adverse impacts if one should fail. Better materials, anticorrosion techniques, and systems for arctic and offshore use must be developed. Emergency response personnel and better emergency equipment and techniques are continuing needs.

Transmodal Programs

Several technologies promise to contribute to more than one transportation mode. Programs underway include: development of automatic controls and automation through the use of microprocessors; development of substitute fuels; combating lagging productivity by increasing transportation efficiency; improving the flow of basic economic commodities; and learning better ways to transport hazardous materials, including better packaging and better trained personnel.

ENVIRONMENTAL PROTECTION AGENCY (EPA)

The main function of EPA's research program is to provide a sound scientific base for environmental regulations. EPA's 1979 research plan focuses on the following areas:

Toxic Substances

This research has two goals: to determine risk levels and to control or minimize exposure. Techniques to assure the quality of research results must also be developed.

Air Pollution

Three problems are receiving particular attention: (1) Interregional transport and transformation of fine particles and other pollutants. Included are animal toxicological tests on the effects of inhalable pollutants. Ozone oxidants and their precursors, as well as organic pollutants, are being studied. (2) The fate and effects of air pollutants. Trace elements are of particular concern, as is the evaluation of the human and economic cost of visibility degradation. As for diffuse and naturally occurring sources, the hazards of fugitive emissions, including dust, must be assessed and better controls developed. (3) Naturally occurring pollutants, of which hydrocarbons are the principal concern. Data are needed to determine the relative importance of natural and man-made air pollutants in causing allergenic discomfort.

Industrial Wastewater

Wastewater treatment is often prohibitively expensive, so to comply with new regulations, industry is making increased efforts in recycling and recovery. However, cost effectiveness must be demonstrated, and better design and control technologies must be developed. Research in this area has three goals: to develop technology for treatment of toxic pollutants; to develop technology to recycle and reuse industrial wastewater, with the emphasis on process modifications in the textile and organic chemical industries; and to collect information for environmental assessments.

Watershed Management

Research is needed on how pollutants can modify a watershed, so that appropriate control methods can be instituted. Nonpoint sources of pollution will be emphasized.

Drinking Water

The goals are: to develop methods to identify and quantify contaminants; to develop treatment technology for controlling organic compounds; to assess health effects of contaminants, focusing on the relationsnips between cancer and organic compounds and between cardiovascular disease and inorganic compounds; and to protect groundwater quality by identifying problems and providing assessment methodologies to state and local governments. The severity of groundwater pollution will be assessed nationwide.

Energy and Environment

Large amounts of data are required to predict and control any adverse environmental impacts of new energy technologies. The major areas of research, in order of priority, are: minimizing the effects of increased conventional combustion, especially coal; minimizing the effects of increased energy extraction, especially coal mining; quantifying the cancer-causing potential of diesel soot; and minimizing the impacts of emerging energy technologies, starting with an environmental assessment of the commercialization of oil shale and following with assessments of coal gasification, coal liquefaction, and other technologies.

Solid Waste

EPA's research in this area has two principal thrusts: development of safe disposal practices, including selecting better sites for landfills and managing the large volumes of industrial waste; and development of resource recovery methods. Research is underway on conversion of waste through biochemical means into such useful products as chemical feedstocks, proteins, and alcohol, and also on reducing production of solid waste through recovery and recycling.

Nonionizing Radiation

Public exposure to nonionizing radiation at microwave frequencies is steadily increasing, but little is known about the possible nonthermal risks to human health posed by low levels. In the near term, EPA research will contribute to decisions on the need to establish environmental guidelines for the general population. In the long term, research will seek to understand the functions of biological trigger mechanisms that result from low and moderate exposures.

Global Pollution

Goals of this research are: to understand how emissions give rise to global impacts; to predict atmospheric movements and concentrations of pollutants; and to identify and assess their impacts on people, environment, and the climate. Air pollution will have priority, with less effort going to research on ozone levels, climate changes, and marine pollution.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (NASA)

NASA's missions can be categorized as: scientific exploration of the solar system; investigation of Sun-Earth relationships; studies of near-Earth space for direct benefit to human welfare; and aeronautics technology. The needs and opportunities arising from these missions fall into eight research areas:

Basic Research

Among topics of interest are applied mathematics and computer science, development of multipurpose sensing instruments, the life sciences, and fluid mechanics.

Space and Terrestrial Applications

Currently, this program has three principal elements: the study of the Earth from space to understand and forecast its environmental behavior, to assess its surface and resources, and to develop a model of the dynamic Earth; the improvement of satellite communications technology; and the demonstration of the capabilities of the space environment in the study of materials processing free of gravitational forces.

Space Science

This program consists of four elements: planetary exploration, astrophysics, and solar, terrestrial and life sciences. The importance of the program lies in the long-range benefits it can be expected to provide, as well as the challenge it gives to the human spirit and intellect.

Space Transportation

The first goal of this program is to provide the efficient, economic space transportation systems that NASA and other users, public and private, must have to achieve their space objectives. The primary means for satisfying this goal into the 1990s will be the space shuttle, spacelab, and upper stages projects. The second goal is to develop support systems that will enhance future capabilities for space transportation. Possibly the most pressing requirement will be to develop larger electrical power packages that would form the bases for larger space platforms.

Space Tracking and Data Systems

For Earth-orbiting missions, one continuing objective is to increase coverage while reducing operational costs. The Tracking and Data Relay Satellite System will take a significant step toward meeting that objective when it begins operating in 1980. A second major objective is to provide the optical tracking capability required by Earth- and ocean-dynamics projects. In planetary and deep-space missions, the principal objective is to improve their navigational accuracy and telemetry data return to maximize the scientific value of the missions. The increasing amounts of data generated will require new data processing facilities.

Space Technology

Present and future space missions will require advanced technology of three major types: first, information systems to provide broader synoptic coverage, wider spectral range, more rapid access to useful information, and—ultimately—lower costs; second, larger spacecraft systems that will require new techniques and components; and third, an enhanced space transportation system.

Aeronautics

Research is intended to help maintain U.S. technological leadership in civil air transportation and in general and military aviation. In civil air transportation, important needs are for safer, more economical, efficient, fuel-conservative, and environmentally acceptable aircraft. In general aviation, the needs are for efficiency, noise reduction, safety, and utility. Improvements in rotocraft will require better efficiency, reduced vibration and noise, lower maintenance costs, and removal of operational constraints due to weather. In military aviation, there are primary needs for integration of flight and engine controls, flight testing of advanced configurations, and development of a broad data base for use in future military aircraft design.

Energy Systems

Current programs utilize both NASA resources and those of other agencies. They encompass three major areas of activity: space utilization, which includes nuclear waste management and satellite power systems; solar terrestrial applications. which include solar heating and cooling, photovoltaic conversion, wind turbogenerators, solar thermal energy conversion, and energy storage; and conversion and fossil energy applications, which include advanced ground propulsion, advanced coal extraction, industrial gas turbines, and phosphoric acid fuel cell systems.

NATIONAL SCIENCE FOUNDATION (NSF)

NSF describes 11 special areas of basic research in which advances over the next five years can be expected to contribute to the understanding and amelioration of a number of problems facing the Nation. The descriptions characterize the national concern, point out scientific opportunities, and mention the readiness of the research community to take advantage of the opportunities.

NSF also notes the need to stimulate a much higher level of scientific and technological literacy throughout the general public. Hence, NSF intends to continue its efforts in this area.

Modification of Plants and Increased Crop Productivity

Recent advances in plant tissue culture and recombinant DNA provide leads to superior plants. Other promising areas are the development of salt-tolerant plants and ecological approaches to the management of crop and livestock systems.

Photochemistry, Photobiology, and Photophysics

Energy supplies could be increased by improvements in photosynthetic efficiency and in construction of artificial systems to increase the capture and conversion of sunlight.

Chemistry of the Brain

Advances at the molecular level could help deal with such problems as obesity, drug and alcohol abuse, schizophrenia, senility, and mental retardation.

Political Economy

Economic and political processes that influence the price and availability of critical resources in international markets are not well understood, nor are the economic and political effects of changes in the prices and supplies of resources. Thus the adequacy of economic projections and the design of effective government policies are limited.

Biogeochemical Cycling

There is need for long-term intensive study of the cycles of critical elements, especially carbon, nitrogen, sulfur, and phosphorus. Research opportunities abound in the areas of interrelationships among those key elements in biota, atmosphere, and terrestrial and aquatic systems. Progress could bring understanding to three global problems of immense magnitude: ozone perturbations, increased carbon dioxide levels, and increased acid rain.

Nonmineral Materials

The products and processes needed to maintain our high-consumption society call for achieving two principal objectives: first, the design of materials with longer useful lifetimes and the capability of being recycled; and second, development of substitutes for non-renewable, energy-intensive, or scarce materials.

Improved Catalysis

Basic research on structure, bonding, and reactions could rationalize the search for new industrial catalysts, helping both individual companies and the U.S. economy as a whole.

Biological and Industrial Waste

A better understanding of waste products could lead to new concepts for recovery of their resource values and at the same time reduce disposal problems and energy consumption.

Geophysics and Geochemistry of Mineral Exploration

Research is required on the natural processes of mineralization to aid in the discovery of minerals at increasing depths where surface indications are obscure. Plate tectonics has already increased our understanding of the genesis of mineralization, while the development of new techniques—aeromagnetism, for example—allows for improved examination of hidden geological settings.

Combustion

Combustion accounts for about 96 percent of the energy conversion processes in the United States, but about half of this is wasted. Thus, even a slight improvement in combustion will mean substantial savings in money and energy.

Properties of Information

Modern society is heavily dependent on obtaining data, synthesizing information, and making decisions. Better understanding of the properties of information and their translation to practical application is particularly significant.

NUCLEAR REGULATORY COMMISSION (NRC)

NRC has identified a number of problem areas in which scientific or technical considerations are of major significance:

Nuclear Reactor Safety

Stress corrosion cracking, two-phase flow phenomena, human behavior, enhanced uranium usage, and risk-assessment techniques will be studied.

Waste Management

As NRC begins to license geological repositories for nuclear wastes, the process will be under close public, industrial, and governmental scrutiny. Studies of bedded salt sites have developed an awareness of safety and migration of radionuclides. A critical part of NRC's technical effort is to develop and test models to determine important design features, geologic effects over time, and data deficiencies. Technical information required for preliminary site reviews covers many areas, including qualitative characteristics, retrieval and monitoring philosophies, and environmental impacts. Particular attention will be paid to mid-term methods that can bridge the time period until ultimate decisions on waste disposal are made.

Safeguards

Methods will be developed to evaluate the performance of existing safeguards against theft and sabotage.

Health Effects

To accurately determine the health effects from exposure to low-level radiation, expensive and long-term epidemiological studies are needed.

Nonproliferation

NRC's efforts on nonproliferation have chiefly supported the Department of Energy's Nonproliferation Alternative Systems Assessment Program and the International Fuel Cycle Evaluation.

VETERANS ADMINISTRATION (VA)

The Department of Medicine and Surgery (DMS) lists seven areas of research and discusses promising approaches in each, including constraints and alternatives. The areas are:

Dysvascular Lower Extremities

DMS will emphasize coordinating the use of various new techniques, including radioisotopic flow and blood-gas measurements, to assess circulatory problems more accurately.

The fundamental changes that occur during aging require investigation. Detailed biochemical and psychological studies of the brain and its reaction to psychologically active drugs should be undertaken.

Schizophrenia

DMS plans to address the need for thorough investigation of these biological factors, including the effects of biochemical treatment. Properly preserved brains from schizophrenic patients are needed for study; the VA is in a good position to establish a "research bank."

Alcoholism

Further study of the biological aspects of this disease is planned, including its effects on the nervous system and the role of heredity.

Comprehensive Health Care

The VA is examining alternative methods of providing comprehensive care, including arrangements similar to a health maintenance organization. Research is planned to test this possibility.

Transplantation and Regeneration

How to initiate, direct, and suppress cell growth, division, and function must be studied to produce information applicable to problems of transplantation and regeneration. However, quick answers are not expected.

Spinal Cord Functions

Electronic means of monitoring cell function in the spinal cord would permit better diagnosis of spinal cord injuries and diseases. DMS plans to address research problems in this area.

Although VA lacks sufficient personnel, funds, and facilities to be a major sponsor of research in the areas described, other agencies could share technical responsibility through intramural research as well as through research under contracts or grants.

Science, Technology and Public Issues: Papers on Selected Topics Commissioned by The National Science Foundation

SCIENCE AND TECHNOLOGY POLICY AND THE DEMOCRATIC PROCESS (*DOROTHY NELKIN*)

The public, now more aware of the risks some science projects present, is less willing to allow technicians and scientists alone to make policy decisions. Many "publics" are seeking to participate in science policy decisions:

- neighbors of a science facility who fear the risks involved;
- recipients of health care who seek a voice in clinical research;
- consumers who seek to maintain individual choice; and
- various groups with ideological interests.

These diverse concerns are reflected in the many controversies over science and technology in which the pervasive issue is who controls crucial policy choices.

Demands for greater participation have coincided with congressional qualms about the increasing power of administrative agencies. Congress has responded in two ways. First, it has enhanced its own ability in technical areas through an expanded technical staff, the Congressional Research Service, and the Office of Technology Assessment. Second, it has passed laws that require greater public participation in administrative agency decisions. Among the options now available to the public are the opportunity to react to draft proposals published in the *Federal Register*, access to government reports under the Freedom of Information Act, and public hearings.

Advisory boards are a participatory channel that provide the public the opportunity to assert some control over decisions. Institutional Review Boards responsible for monitoring research proposals that involve human subjects also include lay members.

Many groups interested in helping form science and technology policy have developed their own channels of participation through the courts and special referenda. These actions in turn have inspired a number of participatory experiments, often outside of usual government channels. One such experiment was the U.S. Forest Service's "code-involve," which analyzed public opinion in the printed media on the proposed use of DDT to protect Douglas firs. Other efforts include "quasi-experiments" in which systematic observations of the actual behavior of individuals are used as evidence of policy choices, mediation procedures, and such citizen review boards as the one set up in Cambridge, Mass., on recombinant DNA research.

Several European experiments offer examples of alternative participatory models, including public review of policy options, public debates, and special educational efforts. These are usually structured more to inform citizens about the value of specific policies rather than to ascertain public opinion.

Special problems face citizens seeking to participate in science policy decisions: the complexity and lack of certainty of technical information, the complexity of Federal and state regulations, and the fuzzy boundaries between questions of technical feasibility and political acceptability. Administrative agencies are ambivalent about citizen involvement because it introduces political controversy and inefficiency.

The demands for participation can affect the application of resources to research, the strength of research institutions, and the way scientists choose their topics and conduct their work. Also, participation can influence the general climate—political, social, and intellectual—in which research takes place. Yet democratic ideals imply that science policy be subject to greater public scrutiny and political control. Indeed, a fundamental source of public concern about science and technology is their implication for political choice. Accommodating these demands of democracy while maintaining the best of scientific learning is a growing challenge that will warrant careful attention over the coming years.

INFORMATION RESOURCES AND THE NEW INFORMATION TECHNOLOGIES: IMPLICATIONS FOR PUBLIC POLICY (*DONALD A. DUNN*)

Information and telecommunication technologies are among the most rapidly changing technologies today. Steady cost reductions in computers and semiconductors have opened a wide range of new applications. Information systems that combine computer power with communication raise national policy issues because they use telecommunication networks that have traditionally been regulated by government. The major policy issue for business is how best to grasp the new opportunities. Consumer policy questions include both new opportunities and need for protection.

Policy issues arise in the creation of new information. The author emphasizes scientific and technical information and considers only certain economic factors:

- the unclear adequacy of patents in competitive, industrialized markets where innovation is rapid;
- direct public investment as an alternative to patent rights to encourage new information;
- the creation of more independent sources of research funding to improve the present system of public investment; and
- new legislation to encourage industry-wide research activity, without antitrust limitations.

Consumer-oriented evaluations of existing programs would provide a basis for improved research planning. Deregulation in many industries may benefit consumers by more rapid introduction of products and services.

Among the most significant recent innovations are person-to-person communication services. Most of these services use the telephone network, and difficulties arise because it is not priced in proportion to its cost. Telephone companies now have little competition in the local distribution market, although radio communication is a possibility. However, present policy trends will probably result in a growing number of choices for users, both among firms and among technologies.

The policy issues raised by electronic message service (EMS) are of particular interest. EMS is a form of message service in which a user types a message on his terminal, edits it, then transmits it, using a time-shared computer system. If EMS is considered a communication service, then according to present law it must be regulated. Legislation pending before Congress would deregulate this class of service. Over the next decade or two, we will see a shift from the use of handcarried mail to electronic mail for transaction services. Because the Postal Service could offer EMS at prices below cost, the EMS industry is alarmed by the possibility of its establishing an EMS network.

Teleconferencing services, including EMS and audio teleconferencing, allow people to work together in different locations. Audio teleconferencing would link conference rooms and remote participants with telephone connections and high-speed facsimile for purposes of document exchange. Because improved telecommunications would allow employees to work at home, the central city may play a reduced role in person-to-person communications.

In telecommunications and information policy, both consumer and business interests favor an open market with as few cross-subsidies as possible. However, a subsidy from heavy users to light users would help achieve universal service. It will be in the users' interest to have all networks interconnect; however, to dominate the market, large providers may resist interconnection.

Innovations in storage and retrieval allow information to be made accessible to a large audience at a time and place of each user's choosing. The library of the future will probably include a system to search the world's bibliographic literature, to immediately provide the text of heavily used references, and to provide by facsimile (within an hour) the text of most other references. Government intervention will probably be necessary to create such a standardized bibliographic search system. A system in London already uses a television set and the telephone network to provide such information as transportation schedules and current yellow pages.

There is a basic consumer interest in having the information storage-and-retrieval market function well. The consumer is ordinarily better off paying directly for such a service than paying indirectly through taxes, as with schools and libraries.

Another information policy issue is the danger of misuse of data about an individual. As more financial services are automated, the market will probably present a range of privacy options to its users. Another issue is whether a person has the right to conduct his financial affairs in secret or to communicate by encrypted dataflows that cannot be decoded. A further question is whether users will be protected from advertisers wishing to use the new medium to reach them.

The other side of the privacy issue is access. The right to access is quite clear in legal proceedings. The issue is less clear when the government collects information without a warrant and without the individual's knowledge. A different kind of access issue arises with information created by research and development. Assuming it is not classified for military reasons, should it be available to foreigners? A number of alternative policies could be followed in this area.

Electronically based financial transactions and records will require a new set of rules and provide novel business opportunities. For instance, more auctions and more sales of perishable goods will be possible.

An integrated view of information policy suggests the possibility of achieving our policy objectives through increased reliance on the private sector and the operation of the market.

COMMUNICATION OF SCIENTIFIC AND TECHNOLOGICAL INFORMATION: IMPLICATIONS FOR FEDERAL POLICIES AND RESEARCH (*MELVIN KRANZBERG*)

The explosive growth of scientific publications after World War II presented scientists with the problem of finding the information they needed. Three responses to that problem were the development of "information science," which is the study of how information is produced, organized, communicated, and used; such secondary information devices as abstracting and indexing services; and computerization of information. However, in their zeal to cope with the publication flood, information scientists originally did not pay adequate attention to informal scientific communication; the structuring of information along familiar, meaningful lines; barriers between scientific disciplines; and language barriers.

Rapid progress in microelectronics has enlarged the capacities of information processing devices and lowered their costs. Secondary information services as well have become more sophisticated. However, to be effective the new information techniques must operate in conjunction with informal, person-to-person scientific networks.

The withering away of traditional publications, due to copying devices and other reproduction systems, will be offset by the flowering of computerized systems. The younger scientists are already becoming more familiar with the computer and new information technology. Electronic substitutes for face-to-face communication—for example, "teleconferencing"—offer hope of maintaining the informal network in the face of energy, transportation, and financial limitations.

A changing role of research and development dictates changes in industry-university information exchange. One suggestion is to have the government encourage different industrial sectors to support long-term research in different universities. But problems remain both in the ownership of information produced in the private sector under government contract and in the dissemination of research results from government laboratories.

While reports to NSF have recommended creation of a national policymaking body for science information, such an institution is of questionable necessity, feasibility, and desirability. In fact, the technical components of information systems have progressed rapidly without governmental direction or subsidy. However, NSF should continue to support basic research on science-technology information systems, especially on the interface of the person with the machine. To match the capabilities of the formal information network with the needs of the informal network, care must be taken to make the system correspond to the structures of the scientific fields and to the outlooks and habits of their practitioners.

The Federal Government should fund development of a catalog of available data bases of scientific and technical information sources. Future programs must do more cross-referencing and indexing between different fields. Disciplines should establish standard nomenclature for computerized indexing, and research should be undertaken on developing computers to respond to natural speech. Translation of foreign reports or their abstracts would be valuable both for science and for military strategic purposes. At least English-language abstracts of foreign items should be included in data systems.

The National Technical Information Service has improved its dissemination of information emanating from the government although it does not incorporate mate rials from all government agencies. The U.S. Patent Office also disseminates technical information; contemplated changes in the patent system should include consideration of effects on information flow.

As powerful corporations combine communication and information functions, thought should be given to the impact of that combination on scientific and technical information communication and to its regulation by the Federal Communications Commission and other agencies.

To strengthen the informal network, the government should encourage scientists and engineers to attend professional meetings and to develop electronic substitutes for travel. Beyond storage and retrieval, the next step in information processing devices is to synthesize the information and work out the researcher's problem directly. Future challenges include applying technology to the ever-growing service sector; applying information services to social and economic problem solving, and using the informat.on systems to increase scientific literacy and thus more widely serve the public.

PRIVACY: IMPACT OF NEW TECHNOLOGIES (*JAMES B. RULE*)

The privacy issue in the past 15 years has focused on personal documentation—dossiers, computer files, and other personal data collected—and used by organizations. While casual observers may attribute the rise of this issue to the computer, new social conditions have also played a role. Among these conditions is the increased importance of recordkeeping bureaucracies in modem societies.

Detailed personal records facilitate "fine-grained" concern with the affairs of individuals on the part of organizations. Personal records enable organizations to deal with people precisely, according to details of their histories and circumstances. The contents of records thus affect the way an individual is treated.

Very large personal data systems may exist without any computing at all. But computerized storage and transmission of information, which have become radically cheaper in the last several decades, make such systems even more feasible. A major protection of privacy in the past has been the unavoidable "waste" of much personal information, something computers now help organizations to minimize. These new "savings" of data can be beneficial, as with medical records, or they can be unpleasant, as in encounters with Internal Revenue Service auditors.

One way personal records injure people stems from their use in arbitrary, inaccurate, and uninformed judgments. Also, some information is so personal that an individual is uncomfortable about its simply being available to others. Finally, data systems can create a climate of intimidation and fear, such that all members of society suffer.

The privacy issue emerged from a series of political skirmishes. Since 1967, more than 50 congressional .. arings have sought principles to guide, and make publicly acceptable, further growth of personal data files. The resulting policies emphasize procedures to help people live more comfortably with their records, instead of taking steps to limit the growth of recordkeeping.

The current approach to privacy protection seeks to apply three principles:

- workings of data systems should be publicly known;
- data should be accurate and complete; and
- individuals should be able to see and correct their files.

The aim is not to prevent collection and use of data but instead to create equitable "rules of the game." Consumers have used the Fair Credit Reporting Act and Privacy Act of 1974 to discover and correct their credit and Federal agency files. However, finding all the record systems containing an individual's files may require considerable effort and inconvenience. We may be already past the point where a person can monitor all uses of data about himself.

But the concept of privacy protection implies more than assuring that one's own records are handled correctly, for we cannot avoid living in a world in which personal data systems enhance the power of government and private organizations to influence individuals. Social and technological forces continue to magnify the importance of the data systems in such power relations. "Rules of the game" to protect privacy may not help if changes in the climate of public life encourage inattention to the rules.

The "need" of organizations for more and more personal recordkeeping deserves more critical attention. Imaginative alternatives to the endless collection of personal data do exist. Organizations could be encouraged to get along without detailed personal information; for example, simplifying the determination of income tax would mean that fewer circumstances would have to be documented.

We face a tension between the demand for more information in the interests of organizational efficiency and the reduction of such demands to lessen pressure upon privacy and individual autonomy. We must recognize that the values of efficiency and technological "progress" sometimes run counter to those of privacy.

Data-using institutions assert strongly that popular demand causes them to seek ever greater amounts of information. However, the public's attitude toward data collecting is a mixture of support and disapproval, according to a 1978 study commissioned by the Sentry Insurance Company. The study found that Americans clearly believe that personal privacy is on the wane although there is no consensus on what to do about it.

The only hope of avoiding continued pressure on privacy is to actively pursue practices that require less information. This would impose costs of varying nature and extent but would not be crippling to the operation of organizations. Auto insurance, consumer credit, and tax bureaucracies, for example, should be able to operate with less personal information.

INFORMATION PRIVACY: A LEGAL AND POLICY ANALYSIS (*ROBERT R. BELAIR*)

Information privacy refers to those standards that promote fairness to individuals in the use of recorded information about them. First, such standards ensure that society is fair in deciding such matters as an individual's ability to obtain employment, credit, insurance, licenses, and other benefits. Second, information privacy doctrines protect an individual's sense of freedom from a "chilling" effect that may result from his knowledge that information has been collected about him. A 1978 survey indicated that three out of four Americans believe a "right to privacy" is akin to an inalienable right; one out of three believes our society to be near that of George Orwell's *1984*, where the government always knows what everyone is doing.

Five important developments are contributing to an information privacy problem.

- First, an individual's financial transactions are more complex, and financial records are inevitably held by such second parties as banks and creditors.

- Second, the government's expanded activity requires it to collect extensive amounts of personal information.

- Third, our society's "near religious faith" in meritocracy requires testing, measuring, and recording personal information on an individual's intelligence, personality, emotional stamina, and character.

- Fourth, recently heightened public suspicion of government and institutional authority makes institutions keep detailed records to document their decisions.

- Fifth, the surveillance and information technologies have matured: advanced electronic listening and watching devices have been developed. Truth detection techniques have also advanced. Most important, automated recordkeeping and dissemination technologies make it possible to collect and handle data efficiently and economically.

It is difficult to overstate the importance of computers in information policy and handling. The amount of information that can be handled has greatly increased. Raw data can be compiled into many configurations for many uses. Information stored in computers can be retrieved easily and cheaply. Computers can link records, eliminating the need for central data banks. Finally, advances in telecommunications have now reduced the privacy issue to "who gets to see what personal data under what circumstances."

The Supreme Court has not been receptive to claims that information privacy is guaranteed by the Constitution, although the concept has common law and statutory recognition. For instance, the Supreme Court decided that contents of bank records need not be kept private. In other cases, the Court recognized a limited constitutional right of information privacy but in most instances ruled against the privacy claimants.

Two common law doctrines protect personal information. One is an implicit promise by the recordkeeper that information will be confidential, as with physicians and bankers. The other penalizes recordkeepers if released information is inaccurate and derogatory or if the method of data collection is overbearing or deceptive.

In the last 15 years, major strides have been made in recognizing and safeguarding informational privacy. The first legislation in 1968 banned most use of wiretapping and eavesdropping devices in the private sector. Next, the Fair Credit Reporting Act set standards for collection and use of personal information by consumer-reporting agencies. The Privacy Act of 1974 required Federal agencies to explain recordkeeping practices, provide subjects with rights of access and rebuttal, comply with restrictions on information collection, meet data quality and management standards, and comply with modest restrictions on disclosure. So far, 12 states have enacted similar statutes, although the Privacy Act has been criticized on a number of grounds.

In 1977, the Privacy Protection Study Commission recommended standards for personal record handling by the private sector and safeguards limiting government access to information maintained by nongovernmental recordkeepers. One of the Commission's recommendations became law in the Right to Financial Privacy Act of 1978.

Thus, a framework for protecting information privacy has been fully articulated, largely implemented at the Federal level, and partially implemented at the state and local government levels. Implementation for the private sector is just beginning.

In the 1980s, the challenge to information privacy will probably continue to grow. There is little prospect that a consensus will soon emerge as to what extent information privacy rights should be protected, although information privacy safeguards should be extended to the private sector. Policymakers should not rely on the participation of subjects as a principal enforcement mechanism, because individuals are in a poor position to police organizations that may be intimidating or with whom they have little contact and whose information practices become increasingly complex. There is a need to improve the effectiveness of confidentiality standards. A Federal law passed in 1974 specifically prohibits certain kinds of third-party disclosures.

Certain principles should be followed in the framing of information collection standards:

- individuals should always know that information has been collected on them;
- individuals should have the right to consent to the collection of data when they are the source of the data;
- individuals, even when they consent, should not be the target of devices that take information from them in a way they cannot control;
- limits should be placed on how data are used; and
- new technology should be monitored.

However, it is unlikely that these steps can be enforced without a new government regulatory agency to oversee them. Therefore, the public may have to choose in the 1980s between effective privacy safeguards and its desire to avoid creation of new government regulatory agencies.

THE ECONOMICS OF PRODUCTIVITY AND SOME OPTIONS FOR IMPROVEMENT (*SOLOMON FABRICANT*)

Productivity growth is critical to the standard of living and the international position of the United States. Thus, the recent decline in productivity growth is a national concern. The processes that affect productivity growth are intricate. Science and technology are important, but other important factors also operate in our market economy.

The information required to improve productivity suffers from gaps and ambiguities. One source of confusion is related to various definitions that are used, including what economists call "labor productivity" and "total factor productivity." The term "productivity" as used in this paper refers to labor productivity. It can be improved through the use of better equipment or materials, reorganization of a firm or industry, or modification of government regulations. Improved productivity entails economic and social costs that must always be compared to the benefits to be derived. Unfortunately, information on costs may be inadequate. Furthermore, what happens to productivity in one industry depends on what happens in the rest of the economy. Finally, the consumer plays a role that is generally ignored in the GNP.

The estimate of productivity is not a simple matter. One special problem relates to the problem of measuring worker output in cases where the end product is not a tangible good. This is particularly true in the service sector of the economy, which is often thought to be of special concern since its productivity growth rate is well below corresponding growth ratio in the non-service sectors. However, the distinctions between the goods-producing and service sectors is not sharp. Productivity and productivity growth vary widely among industries in both sectors and over different time periods. For *most* industries in both the goods-producing and service sectors, productivity growth has been declining. However, since these statistics are based on output measures that are themselves flawed, it is not clear how these declining rates are to be interpreted. This is particularly true in the service sector.

Three main factors affect productivity growth: increases in tangible capital per worker hours, improvement in the quality of labor, and increases in the efficiency with which capital and labor are used in production. Underlying these factors are: the basic causes of increased tangible capital; the education, training, and demographic changes that determine the quality of labor; and technological and other advances that raise labor productivity.

Over 90 percent of industrial research and development (R&D) in the U.S. is performed by the manufacturing industries. However, a good deal of R&D also reaches non-manufacturing industries in the form of equipment, materials and supplies. Economists have attempted to assess in a number of different ways the contributions of R&D to productivity growth. Results indicate a strong positive contribution, but the measures are rough. One problem is the inability to measure accurately the influence of new or improved technology on the quality of the goods and services produced. Another is the difficulty of tracing the contribution of research to improved technology and technology's contribution to economic progress. Finally, information and techniques to measure, assess and adjust productivity figures for changes in the toxic levels and volume of harmful byproducts of technology are lacking.

How strongly forces that affect productivity growth can operate depends on the obstacles that impede them. One obstacle is competition with other national goals (both economic and noneconomic) and with individual goals. A second is curbs on economic freedom, including government regulation, licensing requirements, and building codes. The third is dulled incentives, resulting from taxes, unemployment compensation, and the Social Security system. Four other factors increase uncertainty and risk:

- recent laws and regulations aimed at national goals other than growth;
- rising oil prices since 1973;
- the high and unsteady rate of inflation; and
- fluctuations in Federal support of research and development.

Also making for uncertainty and risk in investment and enterprise is the dearth of good information on current economic developments.

Three factors limit choices in making public policy aimed at improving productivity. First, the primary role in raising productivity has been and will continue to be that of private enterprise. Second, our understanding of productivity is severely limited. Third, the endless variety and incessantly changing nature of the situations that public policy must encompass and for which public officials seldom possess the knowledge required complicate policy determination.

If government is to concentrate its attention on specific industries to raise productivity, it may be best to focus on those with low or slowly rising productivity. Also, productivity in industries heavily dependent upon the government might improve if they were more subject to the forces of competition and the free market. These industries include the aerospace and health care industries.

A number of policy options are available to government to improve productivity. Government should concentrate on *general* policies that can serve to stimulate private enterprise in *all* industries. Expanding the capital equipment of the country, encouraging saving and investment, improving the quality of labor force, encouraging more education and training and the development of better materials and technology—all are steps government can take. Government can also ease regulations and tailor taxes, subsidies and grants with the goal of stimulating productivity. Private monopolistic practices can be curbed. Better controls can be designed and exerted over the quantity, quality, and cost of the output of industries in which government is heavily involved. Research on the economic, social, and statistical questions involved in increasing productivity is also desirable.

TECHNOLOGY AND THE IMPROVEMENT OF AGRICULTURAL PRODUCTIVITY (*HAROLD D. GUITHER*)

Agriculture is the largest industry in the United States, employing 17 million to 20 million people. In 1979, its gross output will be valued at $118 billion to $128 billion. Agricultural exports of about $30 billion per year help reduce the deficit trade balance. The food system uses about 17 percent of all energy used in the Nation, putting that energy into reducing labor by mechanization; boosting the quantity and varieties of food produced; lowering the risks of crop failure or food spoilage; and reducing waste. Farmers' dependence on fossil fuels has grown because, so far, it has made economic sense; they spend 4 to 8 percent of their operating budgets on energy, directly and indirectly.

U.S. farmers are middlemen processing such purchases as machines and fertilizers into food and fiber. Four factors enter into agricultural production. land, labor, capital, and management. Management, which implements new technology, is a major force behind changing productivity.

Technology has been the most important force in increasing farm productivity, which has been closely related to the progress of the entire economy. The infusion of technology has increased output but concentrated it in areas away from markets, leading to lower-quality products and consumer dissatisfaction. However, the consumer has benefited from abundant supplies of a wide variety of foods at lower prices than in other developed countries.

The major options for improving productivity of land can be categorized as crop specialization, shifts within the cropland base, and land-use conversions. For the labor factor, efforts to substitute human or animal labor extensively for mechanical power would result in sharply higher food prices. Options that improve capital productivity and tie in with energy use include.

- improving efficiencies of present technologies,
- conserving fossil fuels by shifting to more use of solar energy;
- producing alcohol from agricultural products, and

- shifting to less capital-intensive methods.

Maintaining adequate food production during the transition from fossil fuels to renewable energy sources poses a major challenge to U.S. agriculture. Fortunately, there are many opportunities to make more efficient use of present technologies. Machinery can be operated more efficiently, and use of pesticides and other chemicals can be reduced without reducing their effectiveness. However, imposition of energy restraints would shift croplands into vegetable production. A number of solar applications may prove economically feasible. A widespread move to solar energy can make agriculture more energy self-sufficient, provide jobs in rural areas, and reduce oil imports. Production of alcohol from agricultural sources is technically feasible, but problems of economics and process energy use are unresolved.

The options for improving productivity through less capital-intensive farming include organic farming. Research into its energy-saving potential is inconclusive. Studies of the Amish lifestyle indicate that more energy is conserved in their homes than in their farms.

Appropriate tax policies to improve farm productivity are much debated. A farmer's ability to benefit from special tax laws is related directly to his tax bracket. Tax shelters are not necessarily a waste of capital resources.

The options for improving production through management include upgrading the education of farm operators, determining the most efficient size of operation using integrated pest management, double cropping, and using computer technology.

U.S. policy has not faced up to how a major shortage (for example, of fertilizer or of fuels) would affect our ability to continue to export agricultural products. Nor is there adequate policy governing competition between imported and domestic products.

The major options for improving productivity of land center around retaining "prime" lands in agricultural production, letting the market allocate all lands, and subdividing large farms into 160-acre units.

No major scientific breakthroughs comparable to hybrid corn or DDT appear likely, although some improvements in productivity can be expected from applications of existing technology and development of new technology. Research needs include long-range weather forecasting, pest control, various areas of plant and livestock research, and a realistic assessment and policy for energy's impact on agriculture. However, if agriculture s exempted from paying higher energy prices, it has little incentive to innovate.

The goals for U.S. agriculture need to be identified. Some decisions may be made on the basis of economic efficiency; others on social equity. Some questions in need of answering: Are small farms warranted? What is the significance of small farmers turning more to direct marketing, albeit in limited numbers?

THE ROLE OF SCIENCE AND TECHNOLOGY IN THE CONTAINMENT OF HEALTH CARE COSTS (*KENNETH E. WARNER*)

The costs of American health care are today's most discussed health care issue. Increases in health care expenditures in recent years have exceeded the general increase in consumer prices by about 50 percent. The Federal Government's share of health expenditures has also grown rapidly, so that the Government feels this rise in costs even more acutely than does the population at large. However, in its response to the health cost problem, the Government fails to distinguish "health" from "medical care."

Health is affected by genetic factors, individual behavior, and environmental conditions, as well as by the use of personal health services. One reason for the increased use of personal health services is to redress the damage done by the other factors. Environmental influences affect large groups of people. Hence, many people could benefit from programs or technology in this area, while the other areas represent primarily individual influences.

Medicine is technologically backward in many respects, one being that medical care continues to be a labor-intensive activity. However, there is general agreement that medical care is now experiencing a technological revolution of unprecedented magnitude that started in the 1940s with the development of antibiotics. Although the dramatic impact of the early "wonder" drugs has not been repeated, research continues to make advances that significantly affect the practice of medicine. Cancer chemotherapy, as well as new drugs to treat pneumonia, ulcers, and epilepsy, will help contain costs.

The emphasis in medical innovation has shifted from biology and chemistry to an equipment-based, engineering technology. The new devices generally are not intended to prevent or cure diseases, but rather to diagnose or control them. Operating costs (particularly personnel) and excessive use of these devices are major causes of increased technology-related costs. Another major cause of increased costs is extensive third-party payments, both by private insurance and by public programs, which make the costs of no direct concern to patient or physician. Currently, over 90 percent of hospital charges are paid by third-party reimbursement. This situation has induced private industry to search for technologies with minimal concern for their cost. Thus, little effort has been devoted to tapping what may be a large reservoir of cost-saving medical innovations. In the future, the nature of reimbursement and regulation schemes may prove more important than specific restrictive practices. Some of these practices have failed to contain costs while others may even have had the effect of discouraging research and development.

General trends in science and technology will also shape the medical technology of the future; for example, use of computer technologies, now limited in medicine, can help contain costs in accounting and record management in private practice and small clinics. Computers used in more direct medical applications may introduce new factors, however. For example, who is liable if a computer "orders" administration of the wrong drug, producing negative effects in a patient?

New medical and surgical procedures and research in such areas as recombinant DNA may help reduce medical costs as well Still, in the immediate future, the cost of medical care will continue to rise at a greater rate than general prices, and technology will continue to contribute to that increase.

Some prevention activities can help contain health care costs. Historically, funding for prevention efforts has been minimal but is now increasing. Genetic manipulation to produce healthier humans is a more distant possibility for reducing costs.

A small investment in persuading people to behave differently—for example, to smoke less and exercise more—can contribute significantly to health with a corresponding decrease in costs. Environmental legislation, with its corresponding reduction in pollution, can also lower costs, as can effective management of toxic substances. Motor vehicle accidents are still another example of an "environmental" problem. Techniques for reducing accidents include behavior modification—for instance, stricter enforcement of speed limits—and such technological aids as car and road safety features. There are also less tangible social, political, and economic impacts on health. For example, the decrease in the primacy of the family has contributed to mental illness.

In conclusion, one must keep in mind that all cost increases are not undesirable The goal of cost containment should be to decrease only the unnecessary or less effective expenditures. However, without a radical change in the basic reimbursement pattern, inflation of medical costs seems likely to persist.

Science and technology in the past appear to have made their greatest contribution to health in nonmedical areas such as better sanitation and public education. For the future, research in biomedicine, epidemiology, and health services, plus increased use of computer and software technology, can all contribute to containing health care costs.

ENHANCING THE CONTRIBUTIONS OF SCIENCE AND TECHNOLOGY IN ENVIRONMENTAL, HEALTH, AND SAFETY REGULATIONS (*EUGENE P. SESKIN AND LESTER B. LAVE*)

In the 1960s, Americans increasingly recognized that a new institutional framework was needed for protecting the environment, health, and safety. The new approach was a radical departure in that it consisted of broad government regulations whose goal was "simply" to protect the environmental, health, and safety (EHS) concerns of all Americans, with little attention to resource requirements or scientific foundation. A host of new agencies was created and vast resources were devoted to rule-making, litigation, and compliance. The mechanism Congress used to attain EHS goals was basically judicial in nature and evidenced naivete about scientific analysis. Although it is values that are fundamentally at issue, science and technology can help to define what EHS effects would be mitigated by proposed actions, what EHS objectives can be attained, and what the most efficient means might be for reaching those objectives. Science and technology will not tell us how safe or cautious we ought to be, but they will serve to clarify the costs and risks associated with proposed actions.

No one is certain how much the myriad new regulations are costing us or whether the benefits exceed the costs. Some estimates imply that a substantial portion of the growth in U.S. economic productivity has gone to finance EHS regulations. However, cost figures do not include estimates of the offsetting gains, or benefits, attributable to the regulations. Unfortunately, relatively little attention has been paid to this side of the equation, partly because the benefits are deemed self-evident. Furthermore, the benefits are less tangible and are frequently spread among a larger population. Yet, the potential benefits from EHS regulations are large and real, and their estimation is essential for rational policymaking.

In trying to achieve their goals, regulatory agencies face the extraordinarily difficult task of balancing protection against costs. Here, science and technology can be both a help and a hindrance. Science and technology introduce useful synthetic chemicals, but some are carcinogenic. They enable us to isolate minute concentrations of substances, but some are not always to our liking, the dioxin TCDD being a prime example.

A multiplicity of goals—broad, complex, and often incompatible—influence policies concerning EHS regulation. One is economic efficiency—that is, achieving some objective with the smallest expenditure of resources. In certain circumstances, a competitive market system will achieve this goal. A second goal is equity. No governmental action takes place without some consideration of the distribution of costs and benefits to important groups of society. A special aspect of equity involves competition among regional or other groups. For example, uniform national pollutant standards avoid giving one region a competitive advantage in attracting industrial plants, despite the fact that the costs and benefits of implementing the standards may vary widely from region to region. Other goals are administrative simplicity and preservation of individual freedom. Another possible goal of regulation frequently cited in EHS areas is that of forcing technologies by setting stringent standards with tight deadlines.

Regulatory strategies now take various forms in our economy. Recent discussions have given greater emphasis to market approaches, rather than to standard setting, to accomplish desired goals. A recent study concluded that strategies making use of such economic incentives as emissions fees and marketable permits cost far less than those that do not.

Another issue is the fact that Federal legislation frequently fails to give the regulators a clear mandate with workable goals. Regulations should be timely and quickly implemented when threats to the environment, health, and safety are involved. However, when billions of dollars of compliance costs are at stake, intense controversy and delays are inevitable. In addition, the resources and time needed to promulgate new regulations limit what agencies can do, making it crucial that they single out the most important problems. Identifying those problems can be especially difficult in the area of toxic substances because such chemicals are usually present in quantities so small that adverse effects are hard to establish.

More information is needed on both costs and benefits of EHS regulations. One source of confusion in estimating costs may be that to economists, "cost" means not just money spent, but opportunities foregone. The estimate of cost associated with regulatory policies would be more accurate if studies were made comparing the actual costs in individual plants with predicted costs. New technology also influences costs. Current estimates are almost inevitably based on existing technology, which tends to overstate costs. Again, retrospective studies would be informative.

Health effects usually predominate in estimating the benefits of EHS regulations. However, other effects—such as those of air pollution on plants, animals, and materials—can be both important and hard to measure. They can be studied by two basic approaches—experimental or statistical. Putting a value on odors, outdoor visibility, and other quality-of-life factors is still at a primitive stage.

Complicating the problem of estimating the health benefits from EHS regulations is the fact that people are exposed to pollutants through a variety of pathways, and that pollutants move and are transformed in the body. Thus, attributing effects to low-level exposures taking place over long periods is extremely difficult. Laboratory experiments are valuable in revealing biochemical and physiological mechanisms. Such research often uses small animals, microorganisms, or cultured human cells. Animal bioassays can demonstrate such qualitative effects as cancer or birth defects and can suggest quantitative, dose-response relationships. However, interspecies differences, difficulty in creating 'real world' conditions in the laboratory, expense, and lack of appropriate statistical techniques are limiting factors. Hence, there has been a great deal of interest in alternative approaches, especially short-term bioassays to identify potentially hazardous chemicals. The most thoroughly studied of these, the Ames test, is based on the relationship between the carcinogenic activity of some compounds and their production of certain types of mutations. It, too, has difficulties.

Similarly, epidemiology has strengths and weaknesses in estimating health benefits. Spurious correlation is always a possibility because many factors simultaneously affect health. Further, identifying mutagens or carcinogens is even more difficult because of long latency periods. Finally, there are serious deficiencies in epidemiological data.

Once the relationship between exposure and health effects is quantified, then one can predict how reductions in exposure would affect health. The next step is translating the predicted changes into monetary equivalents. This extremely controversial problem can be approached by admitting that society has limited resources to devote to life-saving activities and should put them where they will do the most good. A greater understanding of the "psychology of risk" would also be useful. Moving forward in those scientific and technological areas that can enhance EHS regulations requires experimentation to identify the institutional arrangements best suited to carrying out the needed research. Whatever the arrangement, a long-term perspective involving interdisciplinary approaches is needed.

CRIME AND TECHNOLOGY: THE ROLE OF SCIENTIFIC RESEARCH AND TECHNOLOGY IN CRIME CONTROL (*PETER K. MANNING*)

Police work, in terms of everyday functioning, does not appear to have changed much in 150 years, new technology notwithstanding. Police often view new technology as a symbol of power rather than as an aid to crime control. In recent years, new crime control technologies have been introduced, but many of these efforts have failed because of the nature of police organizations and attitudes.

In police work, traditional technology (defined as the means by which an organization transforms inputs into processed outputs) is nonroutine; the material means used are limited and personal; and the knowledge available is nonsystematic situational knowledge rather than casual theories.

The segments, activities, and resources of police organizations pattern the role of technology. Police are highly dependent on information of all types—from citizens (primary information), from once-processed information in investigative units (secondary information), and on information about primary and secondary information already in the system (tertiary information). Unfortunately, the nature of police organization has prevented information from being systemized into a uniform, comprehensible, cross-referenced, and retrievable set of data files.

There are three basic police operational strategies, or patterns of relating to the environment: preventive, proactive (as when police create demand or act on the basis of secondary or tertiary information), and reactive. Each dictates different methods of information gathering and technology use.

Technological innovations have been of two kinds. The first, based on primary information, is primarily in patrol units. In these cases, certain assumptions are made about the relationship between crime and police activity: reduced response time, increased visibility of vehicles, and increased police presence will increase apprehension rates. An important negating factor regarding response time appears to be the time between when a crime is committed and when the victim reports it. Until this time decreases, lowering response time may not help reduce crime significantly because of other factors. Regarding increased presence and visibility, models have been designed to "disperse crime" by diffusing the police presence, but few police departments have tried to use these models. In other experiments, in Kansas City, Mo., and Wilmington, Del., spreading out patrol units failed to deter crime significantly.

The second kind of technological innovation is based on secondary information. The most important examples in this area are case-screening models in detective and juvenile work, in specific cases that experience has shown will probably not be solved. The effectiveness of detectives in case-screening models has been assessed in three studies. Technology was one of the variables studied. The results showed that such factors as training, staffing levels, and organization had no significant effect on arrest levels but could reduce time spent on unsolvable cases. Other studies show similar results.

In short, innovative technology seems to be ineffective in operational police work because while the police are attracted to innovation, they unable to judge its value objectively. However, atte should continue to apply technology to police work i ore efficient manner, although police attitudes and factors over which police have no control—such as weather, citizen-reporting practices, and the unpredictability of criminal events—combine to work against efficient use of new technology. Research in the area is just beginning, however, and only in the future will the precise effects of technology on crime be established

CRIME CONTROL: SCIENCE TECHNOLOGY AND THE INSTITUTIONAL FRAMEWORK (*RICHARD A. MYREN*)

Criminologists generally agree that there is "no single simple cause of crime." The most important element in controlling crime is support of that effort by community members. Also important is that criminal laws stay compatible with the community's value system.

Research is not automatically put into practice. Though scientists (social and behavioral) must strive to be "amoral and value free," they must during testing consider the morals and values of the system in which testing is done. Social scientists can generate new data, organize and interpret them, and predict the impact of alternate actions. Usually, there is tension between researchers and practitioners.

The Science and Technology Task Force, commissioned by the President in 1966, focused attention on and began systematic studies of crime control. About $8 million is spent annually on such research by the National Institute of Law Enforcement and Criminal Justice (NILECJ). In a critique of the way the Institute conducts its research, the National Academy of Sciences in 1977 made 19 specific recommendations, most of which are being implemented. Long-range items now on the Institute's agenda include:

- determinates of criminal behavior, violent crimes and offenders;
- "career criminals";
- use of police resources;
- pretrial process;
- sentencing;
- rehabilitation;
- deterrence; and
- performance standards for criminal justice.

The Institute also administers other programs closely related to its research and development functions.

The National Institute of Mental Health runs a Center for Research on Crime and Delinquency; most of its awards each year go to university-based scholars. Other agencies—including NSF, the Department of Labor and HEW, and the National Academy—are active in the crime and justice area. Other reports with various recommendations have been issued, including a task force report on criminal justice research and development.

Research priorities in criminal justice are set largely by the Law Enforcement Assistance Administration (LEAA) and NILECJ. Their broad parameters are fixed by the NILECJ's perception of the will of Congress. Within those limits, the NILECJ staff, scholars, and practitioners contribute to the final decisions made by LEAA. Little is known about the criminal research community. Results from the enterprise are uneven and difficult to assess. Research can contribute to defining crime and its causes, devising programs to prevent crime, establishing policies for dealing with crime, clarifying the influence of government crime-control programs on people, and planning what to do with those people. Natural and life sciences and technology are useful mainly in detecting crimes and finding criminals. Law and social sciences are more useful for determining why crime occurs and what to do with offenders.

Funding from local, Federal, and private sources ought to be available for such research. Processing issues regarding use of research include: impact of values on criminal justice policies, frequency of policymaking within the political arena, diversity, kinds of people in volved, limited nature of the Federal role, and lack of continuity in Federal policy.

A variety of efforts ought to continue, including any that look into research methods, expansion of "transdisciplinary" programs at universities, better cooperation between academic research programs and crime control planning units in a state, and development of additional research-oriented justice faculties throughout the United States. "There is no field in which generation of new knowledge is more important than in control of crime. Precisely because many of the issues are moral and political, it is imperative that they be informed by scientific research."

SCIENCE AND TECHNOLOGY IN STATE AND LOCAL GOVERNMENTS: PROBLEMS AND OPPORTUNITIES (*IRWIN FELLER*)

There are basic incompatibilities between the way in which the Federal Government is organized to provide science and technology assistance and the factors that influence its effective use by state and local governments. These incompatibilities relate to:

- differences between the "product" orientation of Federal agencies and the needs of state and local governments for "processes";
- different perceptions of what constitutes success; and
- a lack of incentives for Federal agencies to support activities that would assist these jurisdictions in developing effective capabilities to use science and technology.

The root needs of state and local governments in science and technology are much as they have been—to improve the quality and efficiency of their services and to improve the quality of their decisions. A recurring problem is the tendency to treat state and local government concerns as the mirror image of Federal efforts to achieve other valid and overlapping policy objectives. Among these subsidiary Federal objectives are increasing the rate of technological exchange within state and local governments, strengthening policy management capabilities, and applying science and technology to specific problems.

The processes that shape the use of science and technology by state and local governments are more complex than originally envisioned—and so are the solutions. In their efforts to be more systematic in their use of science and technology, state and local governments employ a variety of approaches; for example, governors appoint science advisors, and state legislatures hire staff scientists. These approaches can be classified as research and development, technology use, and scientific information and advice. The various levels of state and local governments differ in the use they make of these three approaches. Local conditions generally determine which work best.

The large-scale Federal interventions of the 1960s have not always lived up to expectations. However, Federal programs for delivering science and technology can point to a number of positive contributions, including:

- fostering an awareness of the gains science and technology can bring;
- creating channels through which state and local governments can communicate with one another; and
- providing a major source of funding for testing innovative projects. More fundamentally, Federal assistance has provided state and local governments with resources they probably could not provide themselves. However, Federal assistance usually requires meeting certain Federal objec-

tives, sometimes to the detriment of state and local objectives.

The tendency of Federal agencies to transfer science and technology "vertically" to state and local counterparts is logical. But when the burden of costs shifts from the Federal level downward, problems can set in. Pressures on Federal agencies lead to product-oriented activities—for instance, promotion of a specific technology in many jurisdictions. But state and local governments most need the "inherently messier" process-oriented programs that, for example, involve use of science and technology in implementing Federal regulations. Moreover, state and local governments may not perceive a Federal agency as a "neutral" transmitter and thus may seek science and technology information elsewhere from a broader-based source. Therefore, there are major gaps between what the "locals" need and what the Federal Government can provide.

Many Federal programs try to build the capacity of state and local governments to use science and technology, a number of which have proved effective. This task is most complex at the state executive level because of the many, varied, and sometimes entrenched programs overseen there. To be effective at the executive level, scientific and technological knowledge must be integrated into a state's policymaking apparatus.

State legislatures have made significant improvements in their use of science and technology in policy issues. At the local level, network-like programs—the most important being the Urban Technology System—still are being evaluated but on the whole seem useful.

Capacity-building programs inevitably encounter two barriers at the Federal level. First, they are designed to assist state and local governments to improve their internal operations, a task which the organizations ought to be doing with their own resources. Second, the capacity-building concept is "fuzzy." Nevertheless, Federal support is necessary. The failures and limitations should be regarded as unavoidable experiences in introducing innovative programs.

SCIENCE AND TECHNOLOGY IN STATE AND LOCAL GOVERNMENTS: THE FEDERAL ROLE (*ROBERT K. YIN*)

A major aim of Federal policy in science and technology is to serve the needs of state and local governments. Reflecting this policy, Federal executive agencies have supported a wide variety of science and technology efforts. However, no overarching Federal strategy has emerged despite continuing attempts to forge one. Although there is little coordination among the numerous Federal efforts, they still fall into two general categories:

- *Technology-push efforts*, in which support has been provided to promote various technological innovations (including hardware, computer systems, and data analysis techniques), each presumed to improve delivery of services in such areas as criminal justice, fire, transportation, public works, health, education, and planning. Federal support has promoted specific innovation *projects*, as well as large-scale innovative *programs*. A typical innovation project, found in education and criminal justice, has focused on identification and dissemination of "exemplary practices"—practices that have been tested at a demonstration site, evaluated in many cases by a third party, and then communicated to other potential users. These project-oriented efforts have increased in their sophistication and scope in recent years. Examples of Federal program support are HUD's Operation Breakthrough and Commerce's Experimental Technology Incentives Program. The results of such projects have been difficult to assess, and in some cases there have been clear failures.

- *Demand-pull efforts*, in which the aim is to build the internal capacity of state and local governments to analyze their own needs and meet their objectives by using science and technology. A leading example of this effort is NSF's Intergovernmental Program. Again, effectiveness has been difficult to assess. As part of the demand-pull approach, Federal agencies have attempted to determine the needs of state and local governments more explicitly. One of the more ambitious attempts is the Intergovernmental Science, Engineering, and Technology Advisory Panel, whose solicitation from state and local interests brought forth a list of some 800 problems that Federal R&D efforts could address. The Panel categorized the responses into 10 functions, each of which was subsequently covered by a task force. The 10, in priority order, are: community and economic development; energy; environment; fire safety and disaster preparedness; the elderly; health and human resources; management, finance, and personnel; police and criminal justice; public works and public utilities; and transportation.

Over the next five years, at least two dominant thrusts will result from the demand-pull approach:

- *Capacity building*. This remains an elusive strategy for three reasons: the most effective strategies have not yet been identified, despite numerous attempts; the assessment of capacity-building efforts is an ephemeral activity at best; and the Federal Government may be in a peculiarly weak position to promote capacity-building efforts.

- *Program analysis*. State and local officials identify program analysis—rather than basic, applied, or evaluation research—as being more helpful in dealing with their policy problems, while Federal agencies are geared toward support of research and development.

Neither of these two thrusts should be considered research, although such agencies as NSF have tended to take the lead role in supporting them. Instead, Federal agencies should reassess their priorities and expand their agendas to deal with state and urban problems more generally, rather than just support state and local governments.

The "self-regulated city"—the concept that the general improvements in the quality of urban life are determined by the collective activities of citizens and organizations—was the essence of the traditional American city of the nineteenth century, as the vigilantes and volunteer fire companies illustrate. This concept may be valid even today. The most relevant research, therefore, should focus on the basic social control and on the economic and demographic trends vital to life and likely to influence the city in the future. For example, operation of neighborhood markets and industrial revitalization seem worthy of further investigation. Taking this broader view of research needs will probably call for a much more innovative approach to policymaking.

A second group of research topics worthy of continued investigation involves innovation, with emphasis on successful innovation rather than on the more traditional orientation toward identifying barriers to innovation. Urban fire services, for example, have successfully implemented a wide range of new technologies.

One criticism of many successful technologies has been that the public tends to be largely unaware of them. Two exceptions involve the paramedic service and the use of breath-testing equipment.

Beyond the substance of the Federal research agenda is the equally important question of future management. Two managerial concerns in particular need attention. One is that although research progresses in a series of small steps rather than in dramatic breakthroughs, Federal agencies are often forced to demonstrate their achievements on a project-by-project basis. New procedures are needed to permit reviewing research on an aggregate basis—synthesizing progress from numerous individual projects, accumulating a consistent set of facts, and making them the basis for actual dissemination and use.

The second concern has to do with improving the technical quality of research on state and local problems. Recent pressure to produce immediate solutions to significant problems has contributed to shortcuts in the normal quality control processes. A major quality control procedure is the publication of results in refereed journals, a time consuming process that has forced many agencies to develop alternative forms of communicating research results. Other quality-control procedures are used in scientific research, but none is a substitute for the more casual indicator of high-quality research—the participation of high-quality people.

THE IMPACT OF TECHNOLOGICAL CHANGE ON THE QUALITY OF URBAN LIFE (*JOHN PAUL EBERHARD*)

For most of the years since World War II, 90 percent of Federal spending for science and technology has been devoted to the three areas of defense, space, and atomic energy. The quality of urban life in the future can be improved by the judicious application of this science and technology although there will be problems with translation and transfer. Thus, some urban conditions will benefit from applications of science and technology, others will not, and still others will likely be aggravated.

Over the next five years, six primary inventions, or bodies of knowledge (those that are the means to other inventions or knowledge), will underlie the driving forces that impact urban life: electronic technology, visual communications, space technology, nuclear energy, life sciences, and systems theory.

Urban areas are neither easy to define nor to encompass in human thought. However, a number of current trends provide some clues to the quality of urban life in the next five years:

- *Age of population*. There is a decided shift coming in the distribution of ages within the population. The most dramatic is a rapid increase in the population over 75, making it necessary to shape the manmade environment to accommodate the sometimes limited physical abilities of the elderly.

- *Income*. In spite of inflation, incomes appear to be becoming more equitably distributed, increasing the middle class in urban areas.

- *Housing*. The price of houses is inflating at record levels, with little relationship to construction costs. Hence, there is little incentive to make technological changes.

- *Other buildings.* Nonresidential building technologies are likely to be changed in the near future as a result of two different, but related, influences: the rapidly increasing cost of fossil fuels and an interest in renovating older buildings.

- *Transportation.* If gasoline shortages continue to plague drivers, they may turn to alternative transportation at a rapid rate or substitute communications for transportation.

- *Communications and information processing.* The first major domestic communications satellite, scheduled to be in business in 1982, will provide substantially new means of electronic communications and information processing. Microprocessors and minicomputers, made possible by chip technology, will impinge on many aspects of the city of the future.

These trends are likely to lead to changes in the following areas:

- *Education.* Education at the elementary and secondary level has the potential to benefit from the new technologies, but countervailing conditions (including an aging population less likely to vote in favor of increased school budgets and the Proposition 13 syndrome) might interfere. Higher education may turn to mass communications to handle the increasing enrollments of more mature persons.

- *Health care and safety.* This area seems likely to continue to improve rapidly. For example, communications satellites connected to computer networks will improve health care data systems. National health insurance will assure that higher costs of medical technology will be managed.

- *Recreation.* Decreasing working hours and increased incomes of urban dwellers have increased leisure activities. However, availability and cost of gasoline are changing vacation patterns.

- *Work.* The number of service workers has increased dramatically and is likely to continue to increase if the fossil fuel situation can be managed satisfactorily.

- *Local government.* Some smaller, more affluent cities (especially on the "sun belt") will probably demonstrate the benefits of new technologies.

A number of issues will emerge from application of the six primary inventions. Probably the clearest technological breakthrough now visible is chip technology. A second and related technology is the communications satellite, which will make possible satellite links that will enable smaller towns and suburbs to compete with larger central cities. The combination of minicomputers and microprocessors linked together into a national network via a communications satellite suggests many applications in metropolitan areas.

Another issue involves energy. As shortages of oil and natural gas grow more acute and prices continue to climb, two basic directions in energy policy seem likely—increases in electricity generated by nuclear energy and in nontraditional alternatives, especially solar energy and conservation.

Life sciences and systems theory are combining to promote change over the next five years. Systems analysis can model the complex urban interactions brought on by the advances in life sciences—for example, increased life expectancy. A final issue involves housing and urban development.

A number of programs are suggested for effectively using science and technology in metropolitan areas:

- a national emergency network for disasters, based on the communications satellite;

- purchase of land with public funds in cities for planned development;

- a major innovative Federal housing program; and

- a program to improve cities for the elderly.

Each suggestion has many policy choices. To forestall "paralysis by analysis," an "experimental innovation incentives" program might be established.

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