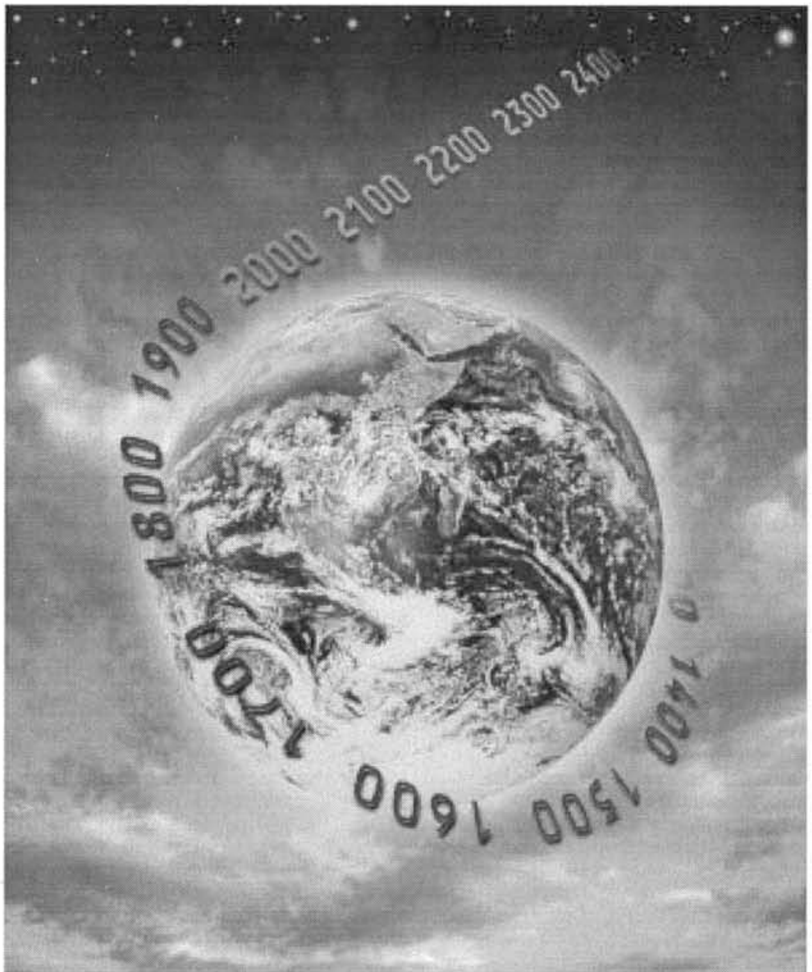
PREPARING FOR THE 21ST CENTURY



SCIENCE AND ENGINEERING RESEARCH IN A CHANGING WORLD

NATIONAL ACADEMY OF SCIENCES
NATIONAL ACADEMY OF ENGINEERING
INSTITUTE OF MEDICINE
NATIONAL RESEARCH COUNCIL

Background

Since Abraham Lincoln approved the Congressional charter of the National Academy of Sciences in 1863, the Academy complex—now made up of the National Academy of Sciences, the National Academy of Engineering, the Institute of Medicine, and the National Research Council—has been advising government about the impact of science and technology on society. The Academy complex provides independent advice to government by appointing committees of experts who serve without compensation, asking these committees to prepare draft reports by consensus, and subjecting these drafts to rigorous independent scientific review before release to ensure their quality and integrity. To avoid potential conflict of interest and bias, careful attention is given to the composition and balance of study committees.

As the 21st century approaches with science and technology assuming increasing importance in society, the Governing Board of the National Research Council has synthesized, summarized, and highlighted principal conclusions and recommendations from recent reports to inform decisions in a number of key policy matters. The resulting series of papers do not address all the intersections of science and technology with public policy, but they do address some of the most important. They are directed to federal administrators, members of Congress, university administrators, leaders of nongovernmental organizations, and all others involved in the development and implementation of public policies involving science and technology.

This paper discusses policies that can strengthen linkages between science and engineering research and national objectives. A separate paper, "Technology and the Nation's Future," focuses on government policies regarding technology development and proposes measures to facilitate the translation of new knowledge to new capabilities.

Previous reports from the Academy complex have had a major effect on science and technology policy. They have helped to improve the quality of science and engineering research in the federal government; sharpened the focus of federally-funded science and engineering efforts; contributed to the creation of important public and private organizations, such as the White House Office of Science and Technology Policy; and shaped a wide range of policies affecting the direction and support of research. The issues summarized in this paper from past reports continue to be relevant to the work of the Academy complex and to the nation.

This document, with direct links to the text of all reports cited herein, is available on the Internet at **http://www2.nas.edu/21st.** A box at the end describes other ways to obtain information on the Academy complex and the topics discussed in this paper.

PREPARING FOR THE 21st CENTURY

SCIENCE AND ENGINEERING RESEARCH IN A CHANGING WORLD

Given the growing importance of *science and engineering research* in meeting national goals, US research needs to remain at world frontiers if the United States is to boost economic productivity and competitiveness, strengthen national security, improve human health, and achieve other national objectives in the next century.

Introduction

Research is defined by Webster's New World Dictionary as "the careful, systematic, patient study and investigation in some field of knowledge, undertaken to discover or establish facts or principles." Science and engineering research conducted in academic institutions, industry, federal laboratories, and elsewhere plays a critical role in raising our standard of living, creating jobs, improving health, and providing for national security. As international economic competition intensifies in the years ahead, this research will be even more important in meeting national objectives.

Several key objectives set forth in Academy complex reports can help guide the development and implementation of public policies in science and engineering research. Among these objectives are the following:

- **Ensure that the United States performs at a world-class level in all major fields of research and achieves preeminence among nations in selected fields.**
- **Convene panels of researchers and other experts to compare US performance in particular fields of research with other countries' performance.**
- **In funding decisions, take advantage of the links between research and the education and training found in academic institutions.**
- **Establish a new budget category known as *federal science and technology* (FS&T) to enable the science and technology budget to be properly considered.**
- **Preferentially fund research projects and individual scientists and engineers on the basis of scientific excellence and importance, rather than institutions, in order to make the research system more responsive to changing opportunities and national needs.**
- **Emphasize independent review, preferably involving external reviewers, in making awards in science and engineering.**
- **Adopt a common definition of misconduct in research that avoids ambiguous categories, while at the same time discouraging such misconduct through a broad range of formal and informal means.**
- **Move toward the use of education and training grants**

The Age of Materials

In 1985, an international team of researchers surprised many scientists and engineers by creating a form of pure carbon that had never before been observed. "Buckyballs," which have a structure similar to the geodesic-dome design pioneered by Buckminster Fuller, are molecules in which 60 or more carbon atoms combine in a hollow shape reminiscent of a soccer ball. Since the discovery of buckyballs, researchers have been intensively investigating possible applications, from catalysis to lubrication to use as superconductors.

From the Stone Age to the Silicon Age, human progress has been measured by the materials that are commonly used in society. Our knowledge now gives us unprecedented control over the structure and properties of materials. Mixed organic and inorganic materials can replace defective parts of the body. "Smart" materials can change their shape or properties in response to the environment. New ways of producing materials are cutting costs and pollution.

So far, we know about only a modest fraction of all the forms and combinations of materials that are possible. The years ahead will bring many new surprises.

For more information:

- *Materials Science and Engineering for the 1990s*, Committee on Materials Science and Engineering, 1989
- *Critical Technologies: The Role of Chemistry and Chemical Engineering*, Committee on Critical Technologies, 1992

to provide support to graduate students.

- **Establish a national database on employment options and trends for scientists and engineers.**
- **Provide the flexibility to redress pay inequities and reward superior performance in compensating federal employees, including scientists and engineers.**
- **Recruit highly qualified scientists and engineers into key policy positions in government.**

Science and Engineering Research Generates New Technologies

Cellular telephones, computers, medical lasers, disease-resistant crops, satellites, biotechnology, optical fiber networks—all these 20th-century technologies and many others can trace their origins at least in part to science and engineering research. New knowledge alone is not enough to achieve major economic, military, or social objectives. But through the combined efforts of business, government, and academic and other nonprofit organizations, new knowledge has been converted into new technologies, new means of production, and new industries. In the process, science and engineering research has enhanced national security, improved human health, produced a stronger economy, and led to a cleaner environment.

Science and engineering research will be even more influential in the 21st century than it has been in the 20th century. No one can predict which technologies will define the next century. But we know that the increasing interconnection of computers into a global network will transform work, communications, entertainment, and education. Greater understanding of biological processes will help to meet the needs of an expanding global population while reducing the adverse effects of humans on the environment. And new treatments and preventive measures for diseases and injuries will improve the quality of life and lengthen the human life span.

The United States has risen to a position of global leadership in part through its strength in science and engineering research. With wise policies for resource allocation and governance, that strength can continue to catalyze US leadership in the next century.

The United States Should Remain at the Frontier in All Research Areas

The call for the United States to stay at the frontier in all areas of science and engineering research reflects the synergistic nature of the enterprise. Many scientific and technological advances have had their origins in research that could not have been predicted to have those outcomes. For example, modern communications is founded on research into the fundamental properties of electromagnetism and electron flow in semiconductors, which resulted in the transistor. Recombinant-DNA technology arose from studies of unusual processes in bacteria. Mathematics, a contributor to engineering and technical arts for more than a century, continues to be at the core of applications as diverse as aircraft design, computing, and predictions of climate change.

Research not only produces new knowledge, it deepens and broadens the experience of scientists and engineers who will go on to apply that experience in many productive ways. The research universities educate the young scientists and engineers who will take jobs in industry, government, and academe. The movement of scientists and engineers among these three sectors diffuses ideas widely and cross-fertilizes different fields of endeavor—often in unexpected ways. The direct interaction of scientists and engineers with each other and with others in society is a particularly effective way of transferring and enlarging new knowledge and technologies.

Scientific information now moves quickly around the world, both through information technologies and through the movement of students and researchers across borders. Because the US maintains a ferment of cutting-edge research across the entire frontier of knowledge relevant to science and engineering, US industry and academia have in place or can readily find the trained personnel they need to take advantage quickly of new opportunities and findings whenever and wherever in the world they occur. This flexibility will become ever more important in the next century, as the complexity of new technologies increases the importance of interdisciplinary knowledge transfers and the pace of change intensifies worldwide.

World-Class Research Is Crucial

Given the growing role of research in meeting national goals, an appropriate objective for US policy is as follows: **The United States should be among the world leaders in all major fields of research and should achieve preeminence among nations in selected fields. (A-1, A-2)** "Among the world leaders" means that the United States should have capabilities (including research excellence and the ability to recognize, extend, and use important research results that occur elsewhere) and infrastructure (including education and personnel) that are not exceeded elsewhere. Of course, other nations will lead the world in specific fields or skills, but by striving for preeminence in selected research fields, the nation can focus its resources on research subjects deemed most promising or important for economic productivity and competitiveness, military strength, human health, environmental protection, or other national objectives.

By being among the world leaders in major fields of research, the United States is "poised to pounce" when an important research development occurs either here or in any other country. When US researchers are working at the world level in all disciplines, they can bring the best available knowledge to bear on problems related to national objectives, even if the knowledge appears unexpectedly in a field not traditionally linked to those objectives. For example, by being among the world leaders in virology, immunology, and molecular biology, US researchers were able quickly to devise a test for HIV antibodies that helped to ensure the safety of the blood supply; and the United States could not have been the home of the emerging biotechnology industry without having been a world leader in molecular biology. US researchers also are able quickly to repeat and extend findings that occur in other countries, such as when high-temperature superconductivity was discovered in Switzerland.

Much knowledge transfer takes place in the graduate science and engineering system. Only by working in the presence of world leaders can students in American colleges and universities prepare themselves to become the future leaders who will extend and apply the frontiers of knowledge. The excitement of working with the world's experts in a particular field also is the best way to attract the brightest young students to that field, thereby ensuring its continued excellence.

The federal government has accepted the general principle of across-the-board leadership, but no mechanism exists to implement it. **The federal government should convene panels of researchers and other experts to compare US performance in particular fields of research with other countries' performance. (A-1, A-2)** These panels could identify emerging fields of interest, recommend budgetary changes, and examine opportunities for international cost-sharing. The panels also could recommend to the executive branch and Congress fields in which the nation should strive for clear leadership.

Achieving national objectives in science and engineering research requires continuous development of human resources. Research that includes an explicit educational component contributes to these objectives more powerfully than research done independently of education. **Government agencies generally should favor funding projects at academic institutions, as opposed to other entities, because they directly link research to education and training in science and engineering. (A-2)**

For more information on staying at the frontiers of science and engineering research:

- A-1. *Science, Technology, and the Federal Government: National Goals for a New Era,* Committee on Science, Engineering, and Public Policy, 1993
- A-2. *Allocating Federal Funds for Science and Technology,* Committee on Criteria for Federal Support for Research and Development, 1995

The US Needs a Unified Budget for Federal Science and Technology

The federal government currently spends more than $70 billion a year on research and development, but about half that amount goes to preliminary production, system development, evaluation, and testing of existing technologies, as opposed to creation of new technologies. **To enable the science and technology budget to be properly considered, a new budget category known as *federal science and technology* (FS&T) should be established. (B-1)** The FS&T budget would be defined as federal funding for science and technology activities that produce—or expand the use of—new knowledge and new or enabling technologies. Spending in this budget category is now funded at about $40 billion per year.

Comparing the institutional distribution of funds for research and development, as traditionally defined, with that in the FS&T budget illustrates the striking difference between the two concepts. Private industry performs the largest share of federally funded research and development as traditionally reported, but most of this work is downstream product demonstration, testing, and evaluation that would not be included within the FS&T budget. When the FS&T category is used, federal laboratories (both in-house and contractor-run) account for the largest share of FS&T (39%), followed by academic institutions (31%), industry (21%), and nonprofit and other institutions (9%).

Note that the definition of the FS&T budget deliberately blurs distinctions between basic and applied science and between science and technology. Complex relationships have evolved among basic and applied science and technology. In most instances, the sequential view of innovation implied by the terms *research* and *development* is simplistic and misleading.

The FS&T budget would be more than just a new aggregation of numbers. Its use would enable the federal government to take a comprehensive approach to science and technology budgeting at key phases in the budgetary process. The president and federal agencies should develop a unified science and technology budget based on assessments of scientific priorities, promising new technologies, and national needs. Congress could then examine this budget as a whole before dividing it among the appropriations subcommittees, and it could monitor the science and technology budget as it passes through various budget steps.

This unified approach to science and technology budgets would allow for tradeoffs among agencies, programs, and research institutions. It would enable government to shift funds toward high-priority fields, reduce or close projects that have become less important, and incorporate the results of program and agency evaluations. Particularly in times of fiscal stringency, a unified budget for science and technology would bring coherence to what has previously been a piecemeal approach to policymaking. (B-1)

For more information on the federal funding of science and engineering research:

- B-1. *Allocating Federal Funds for Science and Technology,* Committee on Criteria for Federal Support for Research and Development, 1995

Vigilance Is Needed to Ensure the Quality of Research

Beyond the allocation of resources to individual fields of research, how can government ensure that the research that it funds is of the highest quality possible? Government and the research community have distilled what we have learned from experience into several important principles.

First, it is important to maintain the ability to change research directions as circumstances change. The pace of discovery has increased, and the time from discovery to innovation and commercialization is becoming shorter in many fields; this makes the flexibility and responsiveness of the research enterprise increasingly crucial. Indeed, the flexibility of the US research enterprise has been one of its great strengths.

To make the research system more responsive to changing opportunities and national needs, government agencies should preferentially fund projects and individual scientists and engineers, rather than institu-

Ensuring the Integrity of Research

The reported incidence of misconduct in research is very low, but any misconduct comes at a high price for both researchers and the public. Cases of misconduct in research breach the trust that allows researchers to build on each other's work, as well as eroding the trust that allows policymakers and others to make decisions based on scientific evidence and judgment.

Breaches of responsible conduct in research can be divided into three categories: misconduct in research, questionable research practices, and other misconduct. The three types need to be distinguished to avoid counterproductive policies and regulations.

Misconduct in research has been defined as making up data or results (fabrication), changing or misreporting data or results (falsification), and using the ideas or words of another person without giving appropriate credit (plagiarism). Such vague definitions of misconduct as "other serious deviations from accepted research practices" risk the possibility that researchers will be accused of misconduct for using novel or unorthodox research methods, even though the methods might sometimes be needed to proceed in research.

Questionable research practices, which include such actions as inappropriate inclusion of an author in a list of authors or maintaining inadequate research records, can erode confidence in the integrity of the research process and waste time and resources. **Researchers and their institutions need to discourage these practices through a broad range of formal and informal means, including education, institutional policies and procedures, and peer review. (C-3)** Government's role in addressing questionable research practices should be to support the efforts of researchers and research institutions to discourage such practices.

Other forms of misconduct are not necessarily associated with scientific conduct and are best handled through generally applicable legal and social penalties.

For more information:

- *Responsible Science: Ensuring the Integrity of the Research Process,* Panel on Scientific Responsibility and the Conduct of Research, 1992
- *On Being a Scientist: Responsible Conduct in Research,* Second Edition, Committee on Science, Engineering, and Public Policy, 1995

tions. (C-1) When the funding commitment is for a specific project of limited duration, the funding in a field can be adjusted relatively easily. To make resources available or reallocate them to meet new opportunities and needs, it is much easier to cut back or eliminate a program of project grants than it is to disengage from the direct support of institutions. Funding people and projects also facilitates the use of independent review to promote the highest quality of work.

In making decisions about funding research projects in science and engineering, government agencies should emphasize independent review, preferably involving external reviewers. (C-1, C-2) In allocating federal funds, the government typically has established broad priorities and criteria for the distribution of the funds. Individual projects have been funded on the basis of assessment of their merit, often with advice from peer reviewers outside government (although there are exceptions, such as research conducted for national-security purposes). The government has solicited this advice in the belief that the public interest is best served by letting scientists decide, on the basis of their experience, which research is most qualified for support. Competition for research support, with evaluation of merit by peers, helps to create a diversity of highly motivated funders and performers. If independent external review is not used for a program, other forms of rigorous merit review, such as the methods employed successfully at institutions like the Advanced Research Projects Agency and Bell Labs, should be utilized.

The trustworthiness of research results is an integral part of their quality. Traditionally, researchers have relied on each other, on the self-correcting mechanisms intrinsic to the nature of research, and on the traditions of their community to safeguard the integrity of the research process. Yet as research has become more tightly linked to national needs, the accountability of researchers and research institutions supported with public funds has become an increasingly prominent issue.

In defining misconduct in research, different government agencies use different definitions, and some of these include ambiguous categories into which unconventional but acceptable research practices could fall. As discussed in more depth in the box on the previous page, **government agencies should adopt a common definition of misconduct in research and avoid ambiguous categories, such as "other serious deviations from accepted research practices." (C-3)** Misconduct in science should instead be defined as fabrication, falsification, or plagiarism in proposing, performing, or reporting research. Misconduct should not include errors of judgment; errors in recording, selection, or analysis of data; differences in opinions involving the interpretation of data; or misconduct unrelated to the research process.

For more information on ensuring the quality of research:

- C-1. *Allocating Federal Funds for Science and Technology,* Committee on Criteria for Federal Support for Research and Development, 1995
- C-2. *Science, Technology, and the Federal Government: National Goals for a New Era,* Committee on Science, Engineering, and Public Policy, 1993
- C-3. *Responsible Science: Ensuring the Integrity of the Research Process,* Panel on Scientific Responsibility and the Conduct of Research, 1992

We Should Encourage a Broad Range of Careers for Future Scientists and Engineers

Scientists and engineers with PhDs and other advanced degrees play a central and growing role in American industrial and commercial life. They contribute directly to the national goals of technological, economic, and cultural development—not only as researchers and educators, but in a wide variety of other professional roles. And as the country responds to expanded economic competition, urgent public-health needs, environmental degradation, new national-security challenges, and other pressing issues, a widening variety of professions and organizations are hiring the roughly 26,500 people who receive PhDs in science and engineering each year (up from 18,000 a decade ago).

Science and engineering PhDs have the qualifications and talents to serve in a broad variety of occupations that will contribute to the economy and society. But a mismatch between the numbers of new PhDs and traditional research-oriented jobs in academe has led to considerable frustration and disappointment among young scientists and engineers. Fewer than one-third of those who received PhDs in science and engineering in 1983-1986 were in tenure-track positions or had tenure in 1991. New PhDs are often spending more and more time as postdoctoral fellows while they wait for permanent jobs to become available. Staff reductions and restructuring in industry and government also have reduced

US Graduate Education in the Sciences and Engineering

More than 600 public and private institutions offer master's or doctoral degrees in science and engineering. In the last year on which data are available (1993), these institutions awarded about 80,000 master's degrees (1993) and 26,500 doctoral degrees (1995) in science and engineering (compared with 72,000 and 19,000, respectively, in 1986).

Most of the growth in the graduate-student population has been due to an increased number of foreign students studying in the United States. This group received 32% of the doctorates in 1992 (up from 19% in 1982). Historically, about half these students leave the United States after receiving their degrees or after serving postdoctoral appointments.

About 450,000 people with doctoral degrees in science and engineering from US universities work in this country. In 1991, 45% worked in 4-year colleges and universities (down from 57% in 1973), 3% in other educational institutions, 36% worked in business and industry (up from 24% in 1973), 6% worked in the federal government, 2% in state and local governments, 3% in hospitals and clinics, 4% in other nonprofit organizations, and the remaining 1% in other occupations.

For more information:

- *Reshaping the Graduate Education of Scientists and Engineers,* Committee on Science, Engineering, and Public Policy, 1995

the number of jobs focused on basic research.

Despite the difficulties in finding jobs in basic research, hiring in other fields has been vigorous enough to keep the overall unemployment level of PhDs relatively low. For example, an increasing number of doctorate recipients are engaged in applied research, development, and management in industry.

Those changes have important implications for the graduate education of scientists and engineers. Graduate training and particularly the pursuit of the PhD traditionally have focused on the preparation of young scientists and engineers for academic careers. But more than half of PhDs now work in nonacademic settings, where they often need to call on a broad range of skills.

This nation has a strong interest in ensuring that talented and skilled people continue to pursue science and engineering careers and are well prepared for the careers that they pursue. Government can help colleges and universities to meet these objectives in several ways. **Federal agencies should move toward the use of education and training grants to provide financial support to graduate students. (D-1)** These grants should be awarded competitively to institutions and departments that work to enhance the versatility of students, both through curricular innovation and through more-effective faculty mentoring to acquaint students with the full range of employment options. Such versatility would enable students to contribute to national goals in academic and nonacademic jobs.

The federal government also should help to establish a national database on employment options and trends in science and engineering. (D-1) The database should be designed and managed by the research community and used both by students and by their advisers to learn more about graduate programs and possible career tracks.

For more information on the research workforce:

- D-1. *Reshaping the Graduate Education of Scientists and Engineers,* Committee on Science, Engineering, and Public Policy, 1995

Outstanding Scientists and Engineers are Needed in the Federal Government

The federal government has a particular interest in science and engineering education: it is the largest employer of scientists and engineers with more than 200,000 holders of bachelor's, master's, and doctoral degrees in science and engineering on federal payrolls. In the past the government has encountered difficulties in recruiting and retaining highly qualified people because of restrictions on pay and professional advancement. The Federal Employees Pay Comparability Act of 1990 gave agencies the authority to ease these restrictions, but implementation of the act has been uneven.

Federal agencies need to have flexibility in compensating employees, including scientists and engineers. (E-1) Although several promising pilot programs are under way, departments and agencies need greater latitude in redressing pay inequities and rewarding superior performance among scientists and engineers. A "senior research and development service," modeled on the Senior Executive Service, could help to maintain a high-performance workforce for senior positions.

At the top of the federal workforce are fewer than 80 presidentially appointed persons who give direction to the entire federal effort in science and technology. **The federal**

government needs to recruit exceptionally able scientists and engineers into its top policy positions to weigh the advice of technical specialists and make key programmatic and policy decisions. (E-2) Disincentives to serve in top positions—for example, unreasonable postgovernment-employment restrictions and inappropriate conflict-of-interest proscriptions—can seriously impede the government's ability to maintain effective policies in science and engineering research.

A particularly important position is that of the president's adviser for science and technology. As was done at the beginning of the Clinton administration, the early designation of the president's adviser for science and technology enables the president to call on this person in recruiting highly qualified appointees to science and technology positions in the federal government. Cabinet secretaries and agency heads also can play important recruitment roles.

For more information on scientists and engineers in the federal workforce:

- E-1. *Improving the Recruitment, Retention, and Utilization of Federal Scientists and Engineers,* Committee on Scientists and Engineers in the Federal Government, 1993
- E-2. *Science and Technology Leadership in American Government: Ensuring the Best Presidential Appointments,* Panel on Presidentially Appointed Scientists and Engineers, 1992

Toward the Future

Leadership in the 21st century will belong to those nations that can capitalize best on change, and science and engineering research has become the most powerful force for change in our society. A strong research capacity will also allow us to deal with a large variety of future challenges, whether national-security threats, environmental problems, medical or public-health emergencies, or crises that we cannot yet predict. Solutions to pressing problems will continue to emerge in unexpected ways from new knowledge.

In summary, our capacity for problem-solving and creative discovery will continue to be essential for keeping the United States in its world leadership position economically, militarily, and intellectually. Prudent stewardship of science and engineering research, as much as any other component of government policy, will dictate how our children and grandchildren will live.

For Further Information:

The World Wide Web site **http://www2.nas.edu/21st** includes up-to-date versions of all the documents in this series and on-line versions of the reports referred to in this document.

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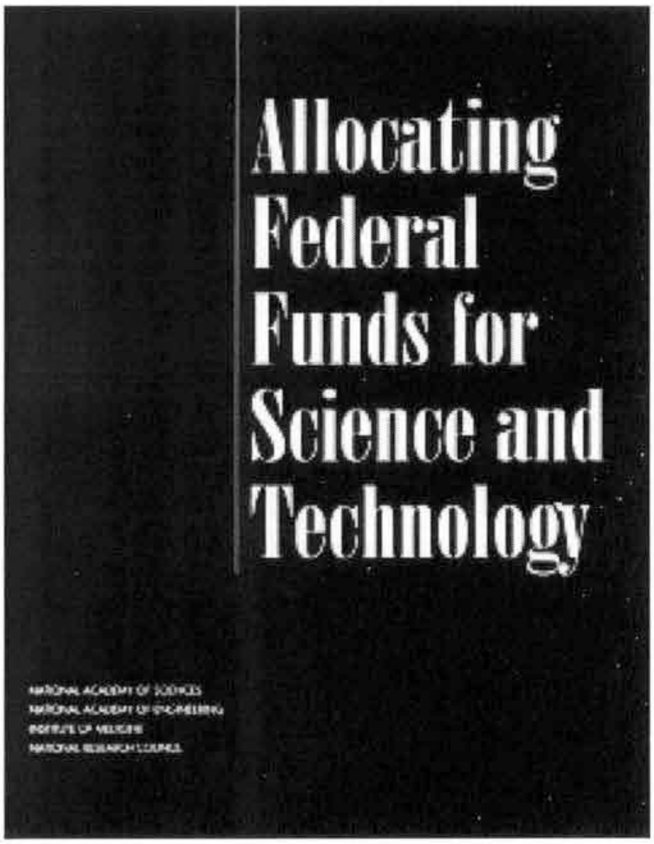

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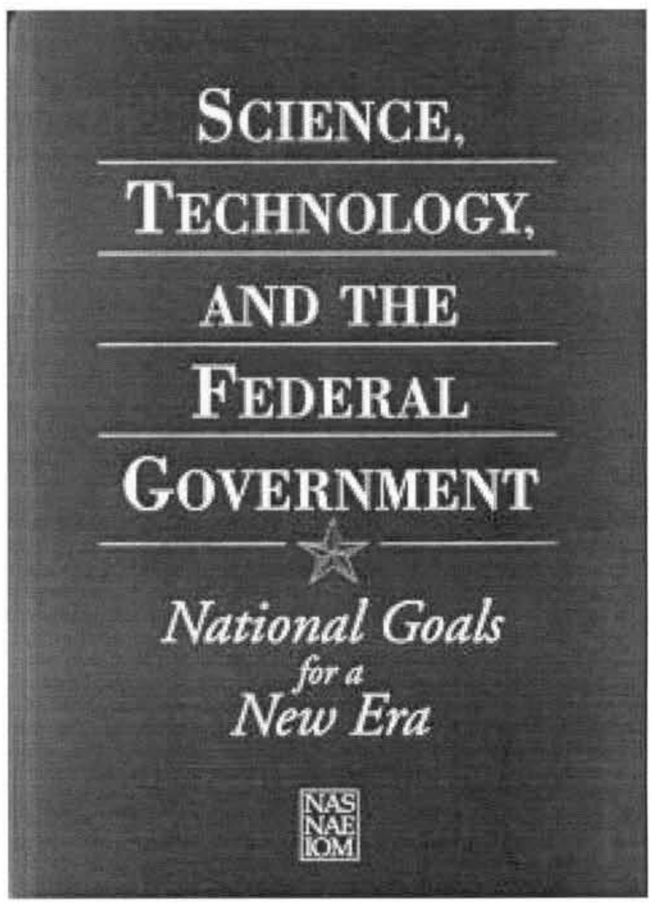

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The **National Academy of Sciences** (NAS) is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. Under the authority of the charter granted to it by Congress in 1863, the Academy has a working mandate that calls on it to advise the federal government on scientific and technical matters. Dr. Bruce M. Alberts is president of the NAS.

The **National Academy of Engineering** (NAE) was established in 1964, under the charter of the NAS, as a parallel organization of distinguished engineers. It is autonomous in its administration and in the selection of members, sharing with the NAS its responsibilities for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. William A. Wulf is interim president of the NAE.

The **Institute of Medicine** (IOM) was established in 1970 by the NAS to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the NAS in its congressional charter to be an adviser to the federal government and, on its own initiative, to identify issues of medical care, research, and education. Dr. Kenneth I. Shine is president of the IOM.

The **National Research Council** (NRC) was organized by the NAS in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the NAS and the NAE in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the IOM. Dr. Bruce M. Alberts is chairman and Dr. William A. Wulf is interim vice-chairman of the NRC.

7. RESEARCH AND DEVELOPMENT EXPENDITURES

Technological innovation has accounted for at least half of the Nation's productivity growth in the last 50 years. We enjoy the fruits of this innovation every day in the many technologies we have come to depend on for our way of life, including lasers, computers, x-rays, teflon, weather and communication satellites, jet aircraft, microwave ovens, solar-electric cells, and human insulin. These advances have generated millions of high-skilled, high-wage jobs and significantly improved our quality of life. Because our investments in research and development (R&D) have paid such rich dividends, the Administration is proposing $72.7 billion in R&D activities in 1998. Of this total, civilian R&D will be funded at $34.3 billion, a $1.2 billion or four-percent increase over 1997 and an 18-percent increase since 1993. University-based research will increase to roughly $12.9 billion, a $529 million or four percent increase over 1997. Chapter Four of the *Budget* includes a discussion that contains more information on R&D activities.

Table 7–1. FEDERAL RESEARCH AND DEVELOPMENT EXPENDITURES

(Outlays, dollar amounts in millions)

	1993[1] actual	1997 estimate	1998 proposed	Dollar change 1997 to 1998	Percent change 1997 to 1998
By Agency:					
Defense	38,035	36,902	35,479	−1,423	−4%
Health and Human Services	9,660	12,323	13,169	+846	+7%
National Aeronautics and Space Administration	8,885	9,182	9,308	+126	+1%
Energy	6,945	6,540	6,746	+206	+3%
National Science Foundation	1,842	2,448	2,448	0	0%
Agriculture	1,455	1,522	1,539	+17	+1%
Commerce	607	885	841	−44	−5%
Interior	636	590	600	+10	+2%
Environmental Protection Agency	519	494	527	+33	+7%
Other	1,736	1,928	2,009	+81	+4%
Total	**70,320**	**72,814**	**72,666**	**−148**	**0%**
By R&D Theme:					
Basic Research	12,625	14,625	14,882	+257	+2%
Applied Research	12,437	14,252	14,540	+288	+2%
Development	42,625	41,408	40,503	−905	−2%
Equipment	NA	973	993	+20	+2%
Facilities	2,633	1,556	1,748	+192	+12%
Total	**70,320**	**72,814**	**72,666**	**−148**	**0%**
By Civilian Theme:					
Basic Research	11,370	13,494	13,729	+235	+2%
Applied Research	8,511	10,212	10,569	+357	+3%
Development	7,374	7,651	8,211	+560	+7%
Equipment	NA	530	539	+9	+2%
Facilities	1,749	1,217	1,282	+65	+5%
Subtotal	**29,004**	**33,104**	**34,330**	**+1,226**	**+4%**
By Defense Theme:					
Basic Research	1,255	1,131	1,153	+22	+2%
Applied Research	3,926	4,040	3,971	−69	−2%
Development	35,250	33,757	32,292	−1,465	−4%
Equipment	NA	443	454	+11	+2%
Facilities	885	339	466	+127	+37%
Subtotal	**41,316**	**39,710**	**38,336**	**−1,374**	**−3%**
R&D Support to Universities	**10,463**	**12,364**	**12,893**	**+529**	**+4%**

NA = Not applicable.

[1] Equipment and Facilities were not collected separately in 1993.