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ABSTRACT

Focusing on the elements of the federal budget process involved in setting policies and priorities for resource allocations that affect the science and engineering base, this report serves to help facilitate a dialogue within the congressional and executive branches of the United States government on science policy. Emphasis is directed to the treatment of research and development in the federal budget and the roles of key federal offices and advisory groups in national policy formulation. The primary objective of this study is to address the question of how science policy advice can be more effectively integrated with the political decision process in setting federal policies and budget priorities for the United States' science and engineering base. Contents include: (1) an overview of the objectives, scope, and methodology of the study; (2) a discussion of the federal role in research and development; (3) a review of the budgeting process and opportunities for change; and (4) an explanation of the organizational framework for developing federal policy for the science and engineering base. Appendices contain information on policy issues, funding considerations, and the proposed creation of a department of science and technology. An 11-page bibliography is included as well as a list of the major contributors to the study. (ML)

United States General Accounting Office

GAO

Staff Study

March 1987

U.S. SCIENCE AND ENGINEERING BASE

A Synthesis of Concerns About Budget and Policy Development

GAO/RCED-87-65

Preface

March 25, 1987

Since World War II, there has been an increasing awareness of the importance and pervasiveness of science and technology in virtually every area of public concern, both domestic and international. In this period, the federal government has played a major role in fostering the advancement of science and technology to meet national needs and to exploit opportunities for enhancing our international leadership and prestige. For the most part, this federal role has been implemented through agency-by-agency planning, budgeting, and oversight, with research and development treated primarily as supporting components of individual agency programs.

The important cross-cutting issues and relationships involved in the U.S. science and engineering base have received relatively little attention. The base comprises the scientific and engineering resources—human talent, knowledge, and infrastructure—that spawn innovations and undergird technological advances to achieve national objectives. By nature, the base involves broad issues and opportunities, often long term in implications, that transcend the interests of individual agencies and programs. Thus, federal planning, priority setting, and oversight focused on the base require a different perspective than is essential for more discrete and shorter term individual agency programs.

Concern about the health of our science and engineering base is increasing. This is due partly to a widely held perception of decreased U.S. leadership and competitiveness in some technological areas and partly to other indicators such as the aging infrastructure of research universities. Leaders from all sectors have raised questions about the adequacy of federal support for the base and the relative priorities for resource allocations reflected in the federal budget.

A major review of national science policy, initiated in the 99th Congress by the Science Policy Task Force of the House Committee on Science and Technology, raised questions about the adequacy of the present institutional framework and processes for formulating national science policy, determining priorities for federal investments in research, and assessing the status and direction of our national scientific effort. The agenda for further study developed by the Task Force specifically expressed the need for the government to reexamine the pluralistic system for budgeting and supporting science, the level of stability of research funding, and the roles of the Office of Science and Technology Policy, the Office of Management and Budget, and advisory committees.

This staff study identifies ways to answer some of the Task Force questions by placing in historical perspective the evolution of policy development for federally sponsored research and discussing alternatives for changing the framework and process for policy and budget decisions affecting the U.S. science and engineering base. Its purpose is to help facilitate a dialogue within the congressional and executive branches on the possible changes.

Our study focuses primarily on the treatment of research and development in the federal budget and the roles of key federal offices and advisory groups involved in national policy formulation and cross-agency governance of the base. It is based largely on a synthesis of previous GAO work on science and technology issues, updated in the context of recent congressional hearings; White House panel reports; and other publications. The study was prepared under the direction of the Resources, Community, and Economic Development Division's Chief Science Advisor, Osmund T. Fundingsland, who has held a leadership role in GAO's science and technology related efforts for many years. Major contributors are listed on page 76.

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Abbreviations

AAAS	American Association for the Advancement of Science
CRS	Congressional Research Service (of the Library of Congress)
FCCSET	Federal Coordinating Council for Science, Engineering, and Technology
FCST	Federal Council on Science and Technology
GAO	General Accounting Office
NIH	National Institutes of Health
NSF	National Science Foundation
OMB	Office of Management and Budget
OSTP	Office of Science and Technology Policy
OTA	Office of Technology Assessment
PSAC	President's Science Advisory Committee
WHSC	White House Science Council

Introduction

The federal government plays a major role in support of a strong national science and engineering base and fosters cooperation among universities, industry, and government to facilitate utilization of research results in both public and private sectors.[1] This resource base undergirds our national security, human health and sociological needs, economic growth, industrial innovation, and international competitiveness.

In recent years, however, partly because of waning U.S. leadership and competitiveness in some technological areas and partly from other indicators such as deterioration in university research instrumentation and facilities and the relative decrease in the number of American students receiving doctorates in science and engineering, concern has grown about the health of our science and engineering base. Questions about the adequacy of federal support and relative priorities for resource allocations reflected in the federal budget are being raised and debated. These concerns are exacerbated by the current federal budget deficit and an austere fiscal outlook for the coming years.

The importance and urgency of federal decisions involving research priorities that may have major impacts on the U.S. science and engineering base and its potential for fulfilling national needs were demonstrated by the Government-University-Industry Research Roundtable.[2] In February 1986 the Roundtable convened a special meeting of some 400 leaders in science, engineering, education, and science policy in Washington, D.C., on the theme, "What Research Strategies Best Serve the National Interest in a Period of Budgetary Stress?" The final report of the Roundtable's meeting contained the following conclusion:

> "If we fail to reallocate funds within the [science and engineering] base or from outside the base, our research system will continue, but it will be of lower quality. If we succeed with internal reallocation but fail to reallocate from outside the base, the quality of the system will be preserved but the system will be down-sized. If we succeed on both fronts, a continuing healthy system will result."

[1]We define the science and engineering base to include the knowledge and expertise derived from, and the institutional relationships and infrastructure involved in, basic research and the portion of applied research which is exploratory and generic to a variety of potential applications. Hence, it is not uniquely related to a single agency mission or technology. The base also includes human resource development through education and research experience in science, engineering, and mathematics. It comprises the scientific and engineering resources that spawn innovations and undergird technological advances to achieve national objectives.

[2]The Research Roundtable, sponsored by the National Academies of Sciences and Engineering and the Institute of Medicine, provides a forum where scientists, engineers, administrators, and policymakers from government, universities, and industry can meet to discuss ways to improve the productivity of the nation's research enterprise.

This study addresses the challenge the country faces in identifying potential improvements in the framework and process for federal policy and budget decisions affecting the U.S. science and engineering base. Thus, it responds to portions of the agenda in a major review of national science policy initiated by the Science Policy Task Force, House Committee on Science and Technology. A number of questions identified for examination in the Task Force Agenda (An Agenda for Study of Government Science Policy, Committee Print 40-860, Dec. 1984) relate to the setting of policies and priorities for the science and engineering base. These include questions about the adequacy of the existing institutional framework and processes for formulating national science policy, for determining priorities for federal investment in research, and for overseeing the status and direction of our national scientific effort. Also, the Task Force Agenda specifically expresses the need and intent to reexamine the pluralistic system for budgeting and supporting science. It specifically cites the need to reexamine the level of stability of research funding, the roles of the Office of Science and Technology Policy (OSTP) and the Office of Management and Budget (OMB), and the use of advisory bodies.

While the Agenda developed by the Task Force suggests the need to reexamine the system, there is an ongoing debate on whether, to what extent, and how feasible it is to improve inter-agency coordination, oversight, and integrated strategic planning. Some believe it is not feasible to do realistic integrated planning in our democratic, pluralistic form of government. Others fear such attempts for science and engineering would lead to central direction and control that would compromise the major advantages of our pluralistic system of budgeting for and sponsoring research. Additional reservations frequently cited to support the view that comprehensive strategic planning is not desirable or feasible are

- A commonly held view that federal support for research can be justified and the results used effectively only if it is deemed directly relevant and essential to a specific agency program or mission. A corollary to this view is the belief that the best way to obtain political support for research funding is to justify it as essential to a particular national program of high priority.
- Resistance from existing power centers against potential erosion of their prerogatives in research management and direction.
- Reluctance to sponsor or engage in long-range strategic planning for a variety of reasons, including the high rates of change in both domestic and worldwide conditions and doubts concerning the reliability of any

predictions; failure to understand that futures research and foresight generally do not develop specific predictions but analyze alternative scenarios that provide context for, and indicate potential consequences of, today's decisions; and doubts concerning the likelihood that either the Congress or the President would give serious attention to future oriented issues because of great political pressures to deal with short-term critical issues and limited tenure of elected and politically appointed leaders.

Although aware of these reservations, we have supported the need for long-range planning and general oversight of federally sponsored research and development (R&D) within the executive and legislative branches and for budget reform to facilitate those processes. While acknowledging that the decentralized system, which features a variety of funding sources and performing institutions for research and education, has been an effective approach, we also have noted that certain essential functions, notably integrated planning; interagency coordination; and comprehensive oversight, have not been adequately achieved. These functions are especially important in the governance of the science and engineering base. Former Comptroller General Elmer B. Staats stated in testimony before the House Committee on Science and Technology in 1975:

"However great the difficulty of formulating a comprehensive national policy and strategy, I believe that an attempt should be made to provide a national policy for planning and resource allocation for science and technology programs . . . . We must also recognize the need for longer term planning of technological needs to better anticipate crises that can be alleviated in part by science and technology . . . . The development of a long-term plan would provide a more rational context for the annual incremental budget decisions . . . . In addition to mission-oriented R&D supported by the various federal agencies and the private sector, we need to establish a long-term investment policy for federal support of basic research and graduate education."

Issues Affecting the Science and Engineering Base

Concerns about policies and funding priorities for the U.S. science and engineering base have been addressed not only by leaders from the science and engineering community but also by industrial executives, political scientists, members of the President's Commission on Industrial Competitiveness, White House Science Panels, and members of Congress in speeches, published papers, and testimony at congressional hearings. These concerns and issues transcend the purviews of individual agencies and require a governmentwide, national perspective.

Our staff study focuses on the elements of the federal budget process and organizational framework involved in setting policies and priorities for resource allocations that affect the science and engineering base. Factors that influence the effectiveness of present institutional arrangements are analyzed and compared with previous arrangements and changes that have been proposed. Our objective is to identify opportunities for improvement.

The following are specific issues that affect the science and engineering base:

- How to set priorities for (1) resource allocation among fields of science and engineering and (2) university facility/instrumentation needs and faculty/student support.
- How to balance (1) support for "big (capital intensive) science" and "little science," (2) research support for defense purposes and needs for industrial innovation and competitiveness, (3) support for major research universities or centers of excellence and "equitable" demographic distribution to less prestigious and usually smaller universities and colleges, (4) support for international cooperative research programs or exchange programs and domestic research, and (5) stability of research funding over a period long enough to achieve meaningful results and flexibility to foster new initiatives.

Although the issues identified above are receiving major attention today, they are not new. In fact, similar issues were debated during the 1970's, when federal support for research was leveling off after a decade of increasing budgets. A list of perennial science policy issues that have never been fully resolved is included as appendix I. It has long been recognized that decisions in the political arena regarding such issues are best made when based on a confluence of perspectives from statesmen of science which encompass socioeconomic considerations and political perspectives.[3] Nearly 25 years ago Peter Drucker, noted management consultant and author, stated that,[4]

[3] We use the phrase "statesmen of science" to characterize scientists who also have developed broader perspectives through relevant experience in policy-level government positions and/or in combinations of administrative, academic, and executive industrial roles involved in national policies for research and education.

[4] Address to the annual meeting of the Corporate Associates of the American Institute of Physics on "New Knowledge in Physics and the Economy."

"Scientific research is no longer tangential to the economy; it is at its dynamic core. Conversely, social developments are no longer tangential to scientific research; they are a major determinant."

Similarly, in testimony before the House Committee on Science and Technology in 1976, former Comptroller General Elmer B. Staats said,

"All of us would agree that never before has it been so essential to integrate science and technology with socioeconomic considerations at all levels of policymaking and throughout the broad spectrum of organizational elements involved. The importance of futurity in present day decisions interrelating scientific, technological, economic, sociological, political, and institutional factors cannot be overestimated."

Objectives, Scope, and Methodology

The primary objective of this study is to address the question of how science policy advice can be more effectively integrated with the political decision process in setting federal policies and budget priorities for the U.S. science and engineering base. While we recognize the importance of strong linkages between the research community and potential users of research results, this study does not include discussion of the roles of federal mission agencies that support R&D, the roles of state government and regional organizations, or subjects such as technology transfer and industrial policy.

For more than a decade, a multidisciplinary staff group within GAO has been performing a variety of assignments involving national science and technology policy issues that transcend the purviews of individual federal agencies. Hence, this study is based to a large extent on previous GAO work, updated in the context of recent congressional hearings, White House Panel reports, and other relevant publications. Accordingly, this study should be viewed as a synthesis of selected options in light of observations from past experience.

In addition, we reviewed relevant government documents and interviewed senior executive branch officials in OMB, OSTP, the National Institutes of Health (NIH) and the National Science Foundation (NSF), as well as nongovernment leaders in science policy, including officials of the National Academies of Sciences and Engineering. We also have reviewed relevant reports prepared by the Science Policy Research Division of the Congressional Research Service (CRS) and the Office of Technology Assessment (OTA) and have interviewed representatives of these congressional agencies. The study was reviewed by officials at OMB, OSTP, NSF, OTA and the National Academy of Sciences. We have incorporated their comments in the text of the study as appropriate.

Premises

In performing our work, we have assumed that certain basic premises dealing with budget formulation and organizational development would have to be recognized when considering changes affecting the science and engineering base.

Regarding budget formulation, we assumed that the treatment of research in the federal budget and the roles of key offices involved in formulation of national policy and determining priorities for resource allocations affecting the science and engineering base are integrally related. Also, a major function of the federal budget is to serve as a policy document which discloses the administration's plans and strategy for implementing priority decisions emerging from major policy considerations.

With or without systematic planning and analysis of alternatives and potential impacts, policymakers are setting budget priorities today that have long-term implications. Any proposed changes in the structure and process for treating research in the federal budget should be compatible with other reforms in the budget process.

With regard to organizational development, we assumed that any organizational change should supplement and build upon the roles of the executive agencies, OMB, OSTP, NSF, or the Congress and its committees and support agencies. As such, we have not included any analysis on the concept of establishing a department of science and technology. Such an analysis would be beyond the scope of this study since we are only presenting changes that would neither require major reorganization of federal agencies nor preempt current roles. Appendix III summarizes published arguments for and against establishing a department of science and technology.

To facilitate the integration of scientific knowledge and perspectives with political considerations in decisions affecting policies and priorities in the governance of the science and engineering base, the following three functions are essential:

Coordination: Policy-level coordination of similar and interrelated fundamental research and education sponsored by two or more agencies. This would identify synergistic relationships amenable to closer interagency cooperation and provide essential information to assess balance in the distribution of resources, complementarity, and undesirable duplication. Communication within the scientific and engineering community at the working levels (through informal contacts, seminars, professional society meetings, advisory committees, peer reviews, technical publications, etc.) is extensive but insufficient alone to fulfill the needs of policymakers. Top policy-level coordination is necessary to resolve "turf" problems and other transcending issues.

Oversight: Monitoring and assessing the condition and direction of the U.S. science and engineering enterprise. This would be derived from general oversight and from statistical indicators, trend data and other evidence, including independent and commissioned panel studies, and oversight hearings. Such oversight would identify current issues and emerging opportunities within and affecting the science and engineering base. It would inventory and evaluate existing resources and growth patterns in relation to national objectives and expectations, thus establishing a context for long-range planning.

Planning: Integrated strategic planning at the highest policy levels. This would include analyses of cross-cutting issues that affect many agencies and performing institutions, and foresight to identify emerging issues and relevant alternative future scenarios. Such planning would also include analyses of anticipated potential impacts of alternative strategic decisions regarding national science and engineering policy and priorities for resource allocations. This function is vital to establish context and guidance for a long-term investment strategy. Even if comprehensive strategic planning cannot be fully achieved, many believe that major R&D policy decisions should give consideration to (1) the effects of the decision on the various dimensions of the science and engineering base and (2) the socio-economic conditions under which the decision will be implemented.

Organization of Study

Our analysis focuses on organizational units with specifically designated roles in oversight, coordination, and strategic planning of the nation's science and engineering resources, and the integrally related treatment of research in the federal budget process. Recognizing the diversity of views concerning the feasibility and desirability of long-range planning and budgeting, this study provides some perspective on opportunities for revising the process for policy and budgetary decisions affecting the science and engineering base. We are suggesting selected changes which, in our view, may alleviate some of the limitations to the existing budget process and organizational framework. The opportunities for change we consider worthy of deliberation involve some revision in the budgetary treatment of fundamental research and some options for minor organizational change.

Chapter 2 provides information about the federal role in research and development. It discusses the pluralistic and decentralized system in place for supporting the science and engineering base in the United States.

Chapter 3 provides information on the budgetary process for the science and engineering base and discusses opportunities for change which involve incorporating more information into OMB's Special Analysis for Science and Technology, simplifying the taxonomy for R&D in the budget process, and establishing multiyear budgeting for at least fundamental research. Respectively, these changes would provide the Congress with more complete data for oversight of the science and engineering base, distinguish fundamental research from R&D uniquely related to individual agency missions or specific technologies, and provide a basis for more stable funding of the science and engineering base. These changes are designed to facilitate interagency coordination, comprehensive oversight, integrated strategic planning, priority decision making, and stability of funding for the science and engineering base.

Chapter 4 provides information on the organizational framework for developing federal policy for the science and engineering base. It suggests organizational changes which focus on strengthening science advice in the Executive Office of the President and developing a policy level structure or mechanism for integrated strategic planning.

Federal Government Plays a Major Role in Supporting Research and Development

The federal government plays a major role in fostering R&D to meet national goals, and some characteristics of the U.S. system are unique among industrial nations. The federal government is the major patron for basic research, funding about 64 percent of the nation's total estimated $14.5 billion spent for basic research in calendar year 1986.[1] For applied research in 1986, the federal government funded approximately $10.3 billion—41 percent—of the nation's estimated $25.3 billion expenditure.

The federal government supports various types of research and development in a number of ways and has at least six general objectives for federal support of R&D:

- Expanding human knowledge and understanding of life and the physical universe.
- Maintaining a strong science and technology base considered to be essential for economic growth, social well-being, and international cooperation and competitiveness.
- Developing technology for government use in federal missions such as national defense and space.
- Establishing a rational scientific basis for health, safety, and environmental regulations.
- Facilitating technological innovation to improve quality and efficiency of public services at all levels of government.
- Sharing support of high-risk, long-range technological innovation essential to future industrial growth and international trade.

The federal government is the major patron of fundamental research (basic and generic applied research) in all fields of science and engineering.[2] This commitment has been assumed by the government because of the broad consensus that such research is of vital importance to the nation and in recognition that the private sector generally under-

[1]Industry funded an estimated 21 percent of the nation's total basic research in calendar year 1986, and universities, colleges, and other nonprofit institutions funded about 15 percent. The federal government subsidizes industrial funding of research by tax credits. Also, in the case of high-technology industrial contractors, the government shares in the costs of contractors' independent research and development.

[2]The term "fundamental research" as used throughout this study is consistent with the definition given in the White House National Security Decision Directive 189, Sept. 21, 1985, as follows:

"Fundamental research' means basic and applied research in science and engineering, the results of which ordinarily are published and shared broadly within the scientific community, as distinguished from proprietary research and from industrial development, design, production, and product utilization, the results of which ordinarily are restricted for proprietary or national security reasons."

invests in fundamental research. This occurs because the payoff from fundamental research is typically long-term and uncertain, and the identifiable return on investment to the sponsor is often less than the value of social return to the public.

Most federally supported basic research and an increasing amount of generic applied research is performed in universities that have graduate programs in science and engineering education, and in university-associated research centers. Thus, research is closely linked to science and engineering education. This is not generally true of other nations. However, the federal government does not assume responsibility per se for the financial viability of universities or colleges, since most of these institutions were established by state governments or private foundations.

The Federal Role Is Pluralistic and Decentralized

In the United States, we have little central planning or direction of R&D—no department or ministry of science. The philosophy underlying the federal role in supporting U.S. science and technology endeavors is pluralism. In this pluralistic system, various agencies, rather than one central authority, delineate areas of interest for support of research and invite proposals from individual scientists and research institutions. A highly decentralized review system, frequently supplemented by peer appraisals, is generally used to judge the merits of research proposals. More than 10 executive departments and agencies with disparate missions sponsor R&D. Most of them support R&D in their own laboratories as well as at universities and in private industry. As estimated for fiscal year 1986, the top six of these agencies sponsored over 95 percent of the R&D supported directly by the federal government.[3]

Although federal agencies selectively support higher level education in science, engineering, and mathematics through grants and fellowships, there is no coherent policy or integrated plan for a federal role.[4] NSF was established especially to sponsor basic research and science and engineering education. It monitors the status of education in science, engineering, and mathematics at all levels and serves as a catalyst to

[3]These are, respectively, the Department of Defense, the Department of Health and Human Services, the Department of Energy, the National Aeronautics and Space Administration, NSF, and the Department of Agriculture.

[4]See, for example, No Federal Programs Are Designed to Support Engineering Education, but Many Do (GAO/PAD-82-20, May 14, 1982), and Renewing U.S. Mathematics: Critical Resource for the Future, Report of the Ad Hoc Committee on Resources for the Mathematical Sciences, National Academy Press, 1984.

stimulate improvements through support of curriculum development, teacher training, laboratory equipment, and other aids to education. NSF also supports generic applied research in areas not supported by other agencies. The National Science Board (the Board) oversees the Foundation, providing policy guidance for basic research and science education.

Central coordination for science and technology is focused in OSTP. This office, established by law in May 1976, assists the President, OMB, and other White House units by analyzing and providing advice on a wide range of policy issues that transcend the jurisdictions of individual agencies. Its role is to provide focus and leadership for interagency coordination and policy guidance. The director of this office is a key administration spokesman for science policy.

Congressional responsibility for science and technology is distributed among approximately 15 House and Senate committees and many subcommittees. On the House side, some eight committees have oversight and/or authorization responsibilities for research and development areas. One committee, the House Science, Space, and Technology Committee, has explicit responsibility for most civilian research. In the Senate, responsibility for the science and engineering base is dispersed among seven committees. The Senate Committee on Commerce, Science, and Transportation, through its subcommittee on Science, Technology, and Space, has broad oversight responsibilities for many aspects of civilian science and engineering research, while six other Senate committees authorize federal agency research in important areas of the research base. For example, NSF research funds are sequentially authorized by the Senate Labor and Human Resources Committee and the Senate Subcommittee on Science, Technology, and Space, while energy research is authorized by the Senate Committee on Energy and Natural Resources.

In overseeing federal science and technology efforts, the Congress also obtains assistance from its support agencies: CRS, GAO, OTA, and the Congressional Budget Office.

The Nature of Research

Research and development occur in a continuum where there are imprecise distinctions among basic research, applied research, and development. In recognition of this, the Board adopted criteria in August 1981 that changed the language used in judging NSF research grant proposals. The criteria removed altogether the idea of "applied research" as a category of investigator-initiated, competitively peer-reviewed research.

Instead, these criteria established a principle that all research proposals be judged on a combination of intrinsic scientific merit and extrinsic technical utility. The words "applied research" were reserved for proposals (usually solicited) directly related to specific programs.

Furthermore, there is not always a linear progression from research to development. Frequently, an empirical invention is conceived and demonstrated by an inventor who has little understanding of science. Such inventions and other technological innovations often stimulate more research to gain fuller understanding of the science involved and to assess implications for variations of the innovation and potential applications. Also, technological innovations in new and improved equipment used for observation and measurement of scientific phenomena facilitate the advancement of research, and computers accelerate data processing and analysis from experiments as well as theoretical calculations. Another exception to the linear model of progression from research through development to application is the direct application of fundamental materials science to process manufacturing, which is rapidly replacing piece-parts assembly manufacturing.

Mission-Targeted R&D and Fundamental Research

The story of lasers illustrates the difference between mission-targeted, or technology-specific R&D, and fundamental research. The invention of the laser was preceded by years of basic research in atomic physics, quantum electronics, optical and microwave spectroscopy, and solid-state physics. Following the first laboratory demonstration of a working infrared frequency laser two things took place. Basic research continued and a great deal of generic applied research was initiated to determine the range of dynamic characteristics and controllable features essential to a wide variety of potential applications, but not unique to any one application. The following are examples of the questions addressed by the generic applied research: Could lasers be designed to work at other frequencies, e.g., in the visible light range; be tuned either mechanically or electronically; be modulated like radio waves; and work at higher power and in gaseous as well as other solid media? The term "fundamental research" includes both the basic and generic applied research described in this paragraph.

Soon after this exploratory fundamental research revealed a wide range of design parameters and potential applications, technology-specific, or mission-targeted, R&D efforts were begun, aimed at specific applications such as optical communication systems, missile guidance, precision altimeters, tunnel alinement, retinal surgery, nuclear fusion, and military beam weapons.

A similar story could be told about fundamental research in biochemistry and biophysics involving genes and molecular structure. Laboratory success in recombinant DNA research and gene splicing prompted extensive generic applied research in biotechnology. Now, mission R&D is aimed toward specific technologies for disease abatement, pharmaceutical applications, agricultural applications, energy conversion, and so forth.

In addition to supporting mission-targeted R&D, federal agencies also sponsor fundamental research in many related fields as well: atmospheric and oceanographic sciences, materials science and engineering, aeronautical and astronautical sciences, surface chemistry and physics, biotechnology, genetic engineering, applied mathematics, artificial intelligence and robotics, tribology, and condensed matter physics, among others. Frequently, generic applied research is interdisciplinary. In each case, an agency funds the R&D deemed essential to its mission. This may include technology-specific R&D and additional fundamental research which may have broader generic implications.

Different Governance Required for Different Types of Research

It is recognized, especially by research administrators, that the science and engineering base requires different governance than agency mission-targeted or technology-specific R&D and industrial products/process R&D since it may be distinguished in several important ways:

- The science and engineering base provides an essential foundation of scientific and engineering resources (knowledge and human capital) that spawn innovations and undergird technological advances which can be further developed and applied through government agency mission-targeted R&D and industrial product/process R&D. The governance of the science and engineering base requires a long-range philosophy and broad national perspective that transcend individual agency R&D programs.
- Fundamental research is serendipitous and unpredictable; hence it cannot be planned, directed, and managed in the same manner as mission R&D. Pay off is uncertain and long term, often over many years. It is widely recognized that fundamental research is most likely to be creative and productive with scientific freedom to explore the unknown and with stability of support over a period of years.

- Regardless of multiple sponsors, fundamental research is synergistic and amenable to competitive approaches, as well as coordination and oversight to assure balance and appropriate allocation of resources.

Notwithstanding the unpredictability of specific project research results and potential impacts, long-range foresight and coherent strategic planning are needed to facilitate judgment concerning general directions of science and technology. Foresight and strategic planning would help political decisionmakers to determine priorities and criteria for allocating resources among the fields of science and consider changes in the infrastructure of the science and engineering base.

Stability of Research Funding

Stability of research funding is essential to the progress of science and engineering. As Vannevar Bush's famous 1945 report, Science: The Endless Frontier, concludes: "Whatever the extent of support [for research] may be, there must be stability of funds over a period of years so that long-range programs may be undertaken."

The previously mentioned Research Roundtable conference report on research strategies for the nation included the following observation:

> "The nature of research makes it particularly vulnerable to instability in support. In particular, a field of research can suffer long-term damage if the best students and young talent are not attracted and retained. Active research teams, once disbanded, cannot easily reassemble. And loss of access to the most advanced equipment is often the difference between world-class and second-rate work."

The White House Science Council Panel on the Health of U.S. Colleges and Universities recently completed a study initiated in May 1982. The report, dated February 1986, highlights a number of findings and recommendations, including the following:

> "Of equal importance with the level of funding is the stabilization of federal support to permit more effective use of financial and human resources. The most ambitious research requires long lead times for preparation and incubation. Research groups are exceedingly fragile; once disbanded, they can rarely be reassembled. In the absence of stability and predictability, important opportunities have been lost, scarce resources have been used inefficiently and, most serious, some of the brightest young minds in each recent generation have been lost to science and technology.

"In order that the university environment be conducive to high-quality research and education; that it be attractive to the best minds; and to increase the effectiveness with which federal funding is used for research, we recommend that:

1. Federal agencies work toward an average grant or contract duration of at least three, and preferably five years.

2. Investigators be free to use up to 10 percent of their grant or contract support on a fully discretionary basis and be permitted to carry unexpended funds forward from one fiscal year to the next."

In an April 1986 letter responding to questions we posed about research funding in federal laboratories, the Director of the Wave Propagation Laboratory at the National Oceanic and Atmospheric Administration stated, in part that:

"Instability of funding is probably the most serious problem affecting generic research areas such as atmospheric science. Many of these problems are directly attributable to the 12 month budget cycle, which is unduly short compared with the multi-decadal duration of generic research programs. The problem is accentuated when (as has often occurred), an agency is on a "continuing resolution" during the first few months of the fiscal year. In this case, no new programs can be started, and expenditure rates are frozen at the average of the previous fiscal year, until the new allocations are assigned. At that time, new programs can start and the program can accelerate throughout the remainder of the year—only to be slowed down again with the start of the new fiscal year, if once again the agency is on a continuing resolution. This on-again, off-again process is obviously destructive of research morale and efficiency, and multiyear planning, funding, and review of research would be a great boon to federal research."

Possibilities for Changing the Way Research Is Treated in the Federal Budget

The treatment of R&D in the federal budget is complex. Each fall, every federal agency submits program estimates including R&D expenditures to OMB for the following fiscal year and projections for 4 additional years. However, they are inconsistent in detail and, with few exceptions, neither the line item categories nor the narrative justifications identify distinctions between categories of research. R&D expenditures are often lumped into broad categories which may include such items as testing, evaluation, demonstration, and general expenses.

OMB requires agencies that sponsor R&D to submit estimates showing breakdowns of research categories—i.e., basic, applied, and development—and R&D facilities. OMB uses this information in preparing its Special Analysis of R&D, which accompanies the President's budget submission to the Congress. The Special Analysis summarizes total basic research of each agency but does not disclose the breakdowns by fields of investigation or disciplines. However, members of Congress may request additional information or data from these agencies.

OMB integrates the total budget package for the President after negotiating final changes with the agencies involved. The President's budget proposal is then sent to the Congress, and the individual agency portions are reviewed by both authorization and appropriation committees and subcommittees in both the Senate and the House of Representatives. As mentioned earlier, specific committees have jurisdiction over individual agencies and programs, and in some cases, these are overlapping.

When the Congress has completed its work, i.e., reconciling the work of all the committees involved, the appropriation bills are forwarded to the President for approval.

The federal budget process creates some difficulties in governing the science and engineering base. These difficulties include several facets:

- The program/agency approach to R&D budgeting that limits interagency comparison by research field or discipline.
- Inadequacy of the federal budget supporting data and information base to facilitate interagency comparisons, oversight, and strategic policy decisions affecting the science and engineering base.
- Constraints on oversight and long-term planning created by the annual budget cycle.
- Restrictions on appropriations that limit stability in multiyear funding of research.

We discuss each of these facets in this chapter and present alternatives for revising the treatment of research in the budget process.

Program/Agency Approach to Budgeting Treats R&D Only as a Component

The budget documents submitted to the Congress by the President are designed primarily to disclose and justify total costs of each major program, including related R&D costs aggregated into broad categories. Most costs for mission agency R&D are not labeled as R&D except for certain program areas in defense, space, energy, health, and the environment. For the most part, congressional budget decisions are, therefore, based on agency missions and programs with little or no attention to R&D classification and interagency comparisons of related and similar research. Even in cases where entire programs are labeled R&D, little attention is given to any distinction between fundamental research and mission-targeted R&D. For example, the Department of Defense (Defense) uses a series of budget categories for accounting purposes. These include 6.1 (basic research), 6.2 (exploratory development, which many construe to be essentially equivalent to applied research), and 6.3 (advanced development). However, in the Defense budget submission to OMB, the 6.1 and 6.2 categories are combined into a line item called "technology base."

Although, as stated in chapter 1, the OMB supplementary budget document entitled Special Analysis of Research and Development summarizes basic research and total R&D by agency, it does not disclose the areas of research by fields or disciplines. Nor does it distinguish between science and engineering base (fundamental) research and mission-targeted R&D uniquely related to individual agency missions. Thus, the budget documents permit congressional committees to examine total agency budgets by programs but do not provide the kind of data and information necessary to compare similar research among programs and agencies nor to identify the dimensions of the science and engineering base.

Federal Budget's Supporting Data Do Not Identify the Base

Supplemental to the official budget documents, NSF prepares a variety of statistical information reports intended for use by policymakers and the science and engineering community. Two annual reports are especially germane to the treatment of R&D in the federal budget. The first report, Federal R&D Funding by Budget Function, published each spring, provides a distribution of R&D programs by agencies and budget functions, for example, national defense, health, energy, and transportation. By categorizing R&D program data by these budget functions, the ratio of R&D funding to total federal funding within each function can be viewed as one measure of the role assigned to R&D in meeting the needs embodied in the functions. Function categories and definitions used in this NSF report are essentially the same as those used in the budget. The second report, Federal Funds for Research and Development, contains detailed tables showing R&D outlays and obligations for a 3-year period (including estimates for the new fiscal year) and 10-year trends. Various tables provide totals and breakdowns for basic research, applied research, and development by agencies and by fields of science. That report is no longer published in printed form, but its data still can be obtained from NSF on computer diskettes or accessed by an on-line computer system. Although that report contains much useful data, typically it has not been published until several months after the official budget documents have been delivered to the Congress.

In 1976 the American Association for the Advancement of Science (AAAS), recognizing the complexities of the federal budget process and the need for the scientific and engineering community to understand the process better and be able to study and debate the federal policies and priorities for R&D as disclosed in the budget, initiated a project to fulfill this need. For a decade, the association has prepared an annual report on research and development, providing data summaries (estimates) with various breakouts of basic research, applied research and development by agency, disciplines, and performing institutions. AAAS obtains its data directly from the research agencies, as well as from OMB and NSF. That report is published in the spring for the upcoming fiscal year and is distributed to participants for review in advance of an annual AAAS R&D Policy Colloquium bringing together leaders from government, universities, industry, and professional societies to address relevant policy issues. Many have expressed the view that these reports are useful and that the colloquium is an excellent forum. However, the tables contained in those reports also fail to distinguish generic from mission-targeted applied research. Although the policy and budget issues addressed at the AAAS colloquium focus primarily on the science and engineering base, the dimensions of the base are not explicitly identified.

Title VIII of the Congressional Budget Act of 1974 requires the Comptroller General to identify and specify congressional committee and member needs for fiscal, budgetary, and program-related information and to develop classification structures for all federal agencies to use in supplying such information to the Congress. After the act became law, we issued two reports that addressed potential improvements in budgeting for research and development. The first report, Need for a Government-wide Budget Classification Structure for Federal Research and Development Information (PAD-77-14), proposed a governmentwide R&D classification structure designed to facilitate inter-agency comparison of similar and related R&D funding. The second, Mission Budgeting: Discussion and Illustration of the Concept in Research and Development Programs (PSAD-77-124), described the concept of mission budgeting and illustrated hypothetically how this approach could be applied to the National Aeronautics and Space Administration, the former Energy Research and Development Administration, and Defense.

Those reports discussed two complementary approaches to improving congressional review and oversight of federally sponsored R&D. Although some experimentation was done by both congressional committees and the Executive Office, neither approach was fully implemented. Both reports provide useful background relevant to the treatment of R&D in the federal budget, but neither identifies the dimensions of the science and engineering base nor the specific data most relevant to its governance.

Effects of the Annual Budget Cycle

The annual budget cycle, including both authorizations and appropriations, imposes a heavy workload on both the Congress and the Executive Office and, together with other urgent agenda matters, limits the time available for oversight and long-range strategic planning. Furthermore, the annual appropriation cycle, combined with constraints on agencies to limit the time period over which funds from a specified fiscal year appropriation can be obligated, causes uncertainty and gaps in continuity of research support.

In April 1979, the House Committee on Science and Technology held oversight hearings on the federal R&D budget. Following these hearings, the Chairman of the Committee introduced H.R. 4490, the Research and Development Authorization Estimates Act. The bill would have provided a basis for a 2-year authorization cycle for federally sponsored R&D. The committee elicited formal comments on this bill in September 1979 and held hearings on its successor, H.R. 7178, in June 1980. We supported these legislative initiatives, providing comments on H.R. 4490 in October 1979 and testimony on H.R. 7178 in June 1980. Favorable comments were given also by OTA, the Congressional Budget Office, the Board, and the National Academy of Sciences. In his testimony, then Comptroller General Elmer B. Staats stated that the proposed legislation would be "an important next step toward multiyear planning, authorization and funding." Further revised and cosponsored by a number of Representatives, the bill was resubmitted as H.R. 7689 and passed by the House

July 21, 1980. It was then forwarded to the Senate, where it died in committee. In June 1981, we issued a report entitled Multiyear Authorizations for Research and Development, summarizing reasons for supporting this legislation. The summary of that report states, in part:

"GAO believes that instituting a multiyear research and development (R&D) authorization process would be an important first step in improving R&D planning, budgeting, and oversight. Such a process would

- give the Congress more time to examine a large number of R&D programs,
- provide the executive branch with time to comply with congressional requests for additional budgetary and planning information,
- increase interaction between the Congress and the executive branch, and
- increase the stability of funding for R&D programs."

The report also stated,

"We . . . believe that a multiyear authorization process could help push the executive branch into acquiring a long-range perspective on R&D. Such a perspective is needed to support any further movement towards long-range R&D planning based upon defined national objectives. In addition, such a process would serve as an important first step towards improving R&D budgeting as a whole and enhancing the stability of R&D programs, especially if a 'rolling' multiyear authorization process, that always projects authorizations beyond the current year, is implemented."

Attempts Have Been Made to Achieve Multiyear Funding of Research Grants

There is a long history of debate on the issue of multiyear funding of federally sponsored research grants. For example, the Subcommittee on Labor, Health, Education and Welfare, Senate Committee on Appropriations, issued a report in 1974 expressing concern about unauthorized multiyear funding of federal programs and reaffirming Congress' position that all grant awards be made on a 12-month basis unless specifically provided to the contrary by the Congress. After further floor debate, the chairman of the subcommittee stated that the Secretary of Health, Education, and Welfare had agreed that all multiyear funding of NIH grants would cease as of May 3, 1974.

More recently, for fiscal year 1985 both the House and Senate recommended an increase in NIH funding for research grants with the intent of increasing the number of grants awarded annually from 5,000 to more than 6,000. Although the final legislation did not specify the number of grants intended for support, it did increase the appropriation for NIH grants by the amount agreed to in conference.

Rather than increasing the number of grants, the executive branch decided to fund only 5,000 new and competing NIH research grants in fiscal year 1985. However, with the increased appropriation and to assure year-to-year stability in the number of grants NIH was able to support as well as to lower fiscal commitments in fiscal years 1986 and 1987, OMB requested that NIH plan to fund some 646 of the 5,000 grants by committing enough fiscal year 1985 moneys to take care of the grantees' estimated needs for 3 fiscal years. An additional 45 of 500 research centers were to be funded in fiscal year 1985 for 2 more years of support.

Subsequently, on February 4, 1985, the chairman of the same subcommittee requested that we determine whether this procedure was legally permissable under existing laws. We responded that according to a statute known as the Bona Fide Need Rule, 31 U.S.C. 1502(a), "[w]ithout express statutory authority, no agency may obligate an appropriation made for the needs of a limited period of time [usually, one year, as in the present case] for needs of subsequent years." Neither the legislation authorizing NIH research grants nor any of the fiscal year 1985 appropriations to NIH institutes supporting research grants provided for multiyear funding. Hence, we concluded that the Bona Fide Need Rule precluded the use of funds appropriated for fiscal year 1985 to fund NIH research grants for more than 1 year.[1]

In May 1985, the chairman of the subcommittee and the Director of OMB agreed to compromise, and in August the Congress passed the 1985 Supplemental Appropriations Act, which specified that NIH fund no fewer than 6,200 new and competing grants and 533 research centers for fiscal year 1985. In addition, the Supplemental allowed for an amount of the 1985 funds already appropriated, not to exceed $20 million, to remain available for obligation until the end of fiscal year 1986. For fiscal year 1986, the appropriations act specified that NIH fund no fewer than 6,100 new and competing research projects. According to an Associate General Counsel at the Department of Health and Human Services, this effectively prevented NIH from funding any new projects for more than 1 year at a time under normal circumstances.

[1]In a February 11, 1986, memorandum to the Department of Health and Human Services, the Justice Department disagreed with our legal opinion. The memorandum stated that "GAO's conclusion that NIH may not lawfully fund grants on a multiyear basis is incorrect."

Notwithstanding our legal opinion that the approach attempted by OMB was contrary to existing law, we continue to support the concept of multiyear funding of research grants.

Uncertainty created by the annual budget appropriation cycle and constraints limiting the time duration of obligations preclude agencies from assuring individual investigators continuous, stable support over a period of years. In the case of NIH, a program manager cannot guarantee an individual research grantee any obligation for funding past 1 fiscal year, although by peer review, a researcher might obtain approval for a project award for up to 5 years. For almost every fiscal year up to and including 1987, NIH has had increasing budgets, minimizing difficulties that could have been imposed by dwindling availability of funds. Even with sequestrations due to the Gramm-Rudman-Hollings Act, NIH has not had to discontinue funded projects, and a senior administrator indicated that whenever it is necessary to adjust for budget reductions, the practice of NIH has been to reduce funds from many projects rather than to discontinue some projects.

In the case of NSF, two kinds of research project grants are available: standard grants and continuing grants. Standard grants have obligation periods equal to project award periods. Currently, standard grants are normally issued for up to 2 years. Much like NIH grants, continuing grants are approved for support for a specified period of time but are usually funded for 1 year with a statement of intent to provide additional support of the project throughout the award period, provided funds are available and the results achieved warrant further support as decided by the program manager.

It is evident that further attempts to achieve multiyear funding for fundamental research would require substantive new legislation or provisions in appropriations acts that would permit appropriations to be spent over more than 1 year. We believe that to be most effective, such legislation would have to be supported by both authorization and appropriation committees.

Opportunities for Revising the Treatment of Research in the Federal Budget

We have identified opportunities for revising the information and data base to facilitate interagency comparisons and governmentwide oversight of proposed research budget allocations and to distinguish dimensions of the science and engineering base from mission R&D unique to each agency. Opportunities are also available through multiyear budgeting or provisions in appropriations acts to enhance strategic planning and stability of funding for fundamental research and education. In this study, we have not distinguished between budgeting for capital expenditures and operating costs. We are considering this in a more comprehensive study of budget reform.

Additional Data Could Be Included in the Special Analysis for Research and Development

First, we address potential expansion of the information and data base, which, with modest effort, could be tried on an experimental basis. Earlier in this chapter we briefly described the types of data presented in NSF's annual report, Federal Funds for Research and Development, which contains breakouts for each agency of basic research, applied research, and development, with research categories further characterized by fields of science involved. As a first step toward improvement perhaps this type of information and data could be incorporated into OMB's Special Analysis. This would require an accelerated effort by NSF, OMB, and the mission agencies to meet the schedule for the annual congressional budget review.

Taxonomy for R&D in the Budget Process Could Be Simplified

Over the years, the need for uniform or standard taxonomy for types of research or phases in the research continuum has sparked much debate. In December 1979, NSF sponsored a symposium on "Categories of Scientific Research" and published papers presented by leaders from government, industry, and academia. In his introduction to the symposium's report, Dr. Richard Atkinson, Director of NSF, stated that:

> "No consensus was expected about the most appropriate ways to describe the complexity of the research continuum, and none was forthcoming. However, the participants agreed that there is a type of scientific research characterized by the generalizability of its results and the expected length of time likely to elapse before its benefits are realized that must be pursued in order to maintain the infrastructure that underlies all of science and technology."

As a second step toward improving planning and oversight of the science and engineering base, we consider an approach for simplifying the taxonomy for R&D in the federal budget, especially in the OMB Special Analysis for R&D and in NSF supporting documents. The idea would be to stop using the three conventional terms—basic research, applied research, and development—and substitute a new taxonomy consisting of only two categories defined earlier in this report:

- fundamental research (combining basic and generic applied research), and
- mission-targeted R&D.

Our use of the term "fundamental research" is consistent with Dr. Atkinson's observation stated above.

The primary purpose of this change in taxonomy would be to identify and define the dimensions of the science and engineering base as distinguished from R&D that is deemed uniquely related and essential to individual agency missions. Essentially, the alternative would involve an additional step to separate the generic portion of the current applied research category and combine it with basic research into a single category called fundamental research and subsume the mission-targeted applied research portion into the technology-specific mission R&D category. This distinction would be intended only to facilitate oversight, interagency comparison, and long-range planning of research which is inherently exploratory, long range, and synergistic but not uniquely related to the mission or programs of a single agency. It would not preempt any agency from continuing to support both mission R&D and fundamental research as appropriate to help meet both short-term and future agency objectives. Federal support of fundamental research (especially the portion conducted at universities) usually includes some support for science and engineering education, e.g., graduate student assistants. Other federal support for such education could be identified separately as NSF is now doing or could be reported in the budget as part of the fundamental research category.

One advantage to using the fundamental research budget category as defined here is to facilitate comparison, e.g., via the NSF surveys, with industrially supported research. Very few industrial firms distinguish between basic and applied research, and instead use such terms as pioneering, generic, general, exploratory, or fundamental research. Currently, to obtain research data from industry (primarily for comparison with federal funding of basic research in universities), NSF adds a special paragraph to the survey questionnaire for industrial use in interpreting what portion of a company's research can appropriately be classified as basic.

The distinction between fundamental research and mission-targeted R&D also is quite similar to the approach used by some large technology-intensive industrial firms. Corporations using this approach do not distinguish between basic research and exploratory applied research, but they do separate corporate-sponsored research (whether they call it generic, pioneering, general, or exploratory research) from shorter term product and process R&D supported by company divisions engaged in product manufacturing and engineering services. Corporate-sponsored research is based on long-term investment strategy, and usually is small, for example, less than 10 percent of total company sponsored R&D. Hence, it tends to be insulated from fluctuations in the economy and the short-term variations in the marketplace. Product and process R&D supported by operating divisions are more likely to vary from year to year, depending on the projected sales outlook and the competitive market position of the sponsoring division.

There is a rather widespread notion that because of industrial profit motives, it is not sensible to compare government and industrial approaches to R&D planning and budgeting. However, this view fails to recognize that in the type of large corporations mentioned in this study, the corporate-sponsored fundamental research, although constrained by broad dimensions of business strategy, is performed in cost centers which are budgeted separately from operating division profit centers and have no direct profit responsibility. Of course, they are expected over a period of years to spawn innovative technological options that feed profit-making divisions engaged in manufacturing and commercial services, as well as provide scientific advice and problem-solving assistance to operating divisions as needed.

We believe that some features of this industrial approach are adaptable to the federal government's approach to planning and funding fundamental research and mission R&D. For example, typical questions faced by technology intensive firms (see app. II), with minor word changes, are essentially the same as questions continually addressed by the federal government. Appendix II also includes industrial considerations commonly used for allocating corporate resources among fields of investigation.

Many of these are analogous to and perhaps could be adapted for government planning and resource allocation for federal support of the science and engineering base.

In April 1986, OTA published a report entitled Research Funding as an Investment: Can We Measure the Returns? In that report, OTA compares research decisionmaking in industry and government with particular attention to the use of quantitative methods. The executive summary of that report states, in part:

"In industry, where one might expect quantitative techniques to prevail due to the existence of a well-defined economic objective for the individual firm or business, OTA found great skepticism among research managers about the utility of such techniques .... Peer review dominates program evaluation in industry .... At the basic research end of the spectrum, industry's project selection techniques tend to be quite subjective and informal, supplemented occasionally by scoring models. At the applied research or exploratory development stage, simple, unsophisticated selection procedures, based on a page or two of qualitative information or a simple rating scheme, dominate.

"In the 1970's, corporate strategic planning came into vogue, and technological change came to be recognized as an integral part of corporate planning. R&D planning and budgeting was integrated into the overall corporate strategic effort. Many firms set up committees and other formal mechanisms to assess long-term technical opportunities, establish broad goals for the commitment of resources, ensure that resources are properly allocated to develop the technology necessary to support those goals, approve major new product programs, and monitor progress.

"[Private sector corporate] budgeting for research and development shares many of the characteristics of traditional federal budgeting."

Although some of the officials we interviewed, e.g., at OMB and NSF, had reservations about introducing this change in taxonomy, others at the National Academy of Sciences and AAAS, and private corporate executives supported the concept as a potentially useful step. Of those who supported the concept, some still were skeptical about the feasibility of making the budgetary change. OMB officials did not think the change would be worth the effort it would involve, while officials at NSF opposed it. NSF officials stated that under our simplified taxonomy, (1) the agencies would still interpret the distinctions between fundamental research and mission research subjectively, (2) the change would take many years to implement fully, and (3) it would "cost the long-term data base," i.e., disrupt longitudinal data and trend analyses. It is our opinion that the reclassification we suggest would be more reflective of research categories. The advantages of introducing an appropriate taxonomy to identify the dimensions of the science and engineering base would have to be weighed against the disadvantages of losing some detail in the traditional longitudinal data.

Four difficulties anticipated in adopting a revised two-category federal budget classification structure are (1) defining the categories clearly enough to minimize the gray areas, (2) making adjustments from time to time to accommodate newly emerging research areas, especially in interdisciplinary fields, (3) dual tracking of data by old and new classifications for a few years to provide continuity and orderly transition of trends and statistical reporting, and (4) overcoming possible reluctance to cooperate by R&D agencies. The first difficulty is inherent in any budget classification structure, and the second and third would be true of any change. With regard to the fourth difficulty, R&D agencies naturally would be reluctant to acknowledge that any portion of their sponsored research is not essential to their mission, or, on the other hand, in the face of budget austerity, they might try to transfer all fundamental research to NSF. Resolving these problems would require strong leadership from OSTP, as well as extra efforts by the R&D agencies and NSF, with cooperation from OMB.

Multiyear Budgeting Could Be Reconsidered for at Least Fundamental Research

A third step would be to consider using multiyear budgeting to permit more time for oversight and strategic planning and to enhance the stability of research funding. Once the dimensions of the science and engineering base have been defined by the fundamental research budget category, another previously proposed step in budget reform could be reconsidered. Perhaps now is an appropriate time for the Congress to again consider legislation to establish a multiyear authorization cycle for at least fundamental research and education, key elements in the science and engineering base that require governmentwide oversight, long-term planning perspectives, and continuity of funding over a period of years. If the equivalent of H.R. 7689 during the 96th Congress (described in this chapter) were introduced in modified form, limiting multiyear authorization to the science and engineering base portions of the budget, we believe another change suggested for congressional consideration by us in 1981 would be appropriate.[2] This would be to include a "rolling clause" that would continually project authorization 1 year beyond the existing cycle. Such a rolling clause would permit continued funding of research grants for 1 year beyond the end of the authorized cycle, thus eliminating sudden disruptions at the end of a cycle. Multiyear authorization could also lead to a multiyear funding cycle for the science and engineering base and relieve annual budgetary workloads sufficiently to foster more oversight and strategic planning in both the executive and legislative branches.

[2]Multiyear Authorizations for Research and Development (PAD-81-61, June 3, 1981).

Whether or not a multiyear appropriation cycle can be achieved, perhaps provisions could be included in appropriations bills that would relax constraints imposed by the Bona Fide Need Rule and allow agencies discretion to obligate funds appropriated for fundamental research and education in a given fiscal year to support selected multiyear grants, thus enhancing the stability and continuity of funding. Under this approach, the funds obligated in a given fiscal year could be expended incrementally over a multiyear period for selected research and education grants. Since not all funded projects would begin or end in a given year, the agencies would have discretion to decide whether or not to renew some grants and to initiate new starts in promising areas.

Possible Changes Within the Current Organizational Framework

Since NSF's establishment in 1950, the executive branch has used a number of different organizational arrangements to foster interagency coordination, oversight, and planning for science and technology. The effectiveness of these arrangements has depended to a large extent on the degree of presidential interest and support they have received.

On the legislative side, since OTA was created in 1972, the Congress has had its own science and technology advisory office. Along with its other support agencies, the Congress uses OTA as an information resource for identifying science and technology issues and analyzing alternative policy initiatives.

In this chapter, we (1) provide a historical overview of science advisory arrangements from 1950 until 1976, focusing on the ability of executive branch arrangements to coordinate, oversee, and plan for the science and engineering base, (2) describe the current organizational arrangement, focusing on OSTP, and (3) present several organizational alternatives designed to improve the current arrangements for coordination, oversight, and integrated strategic planning for the science and engineering base.

As discussed earlier, we have not included any analysis on the concept of establishing a department of science and technology. We have, however, summarized the published arguments for and against such a department in appendix III.

Historical Overview: Focus of Science Advice to the Executive Office Has Changed From 1950 to 1976

For purposes of this study, we have identified five periods (including the current period) since 1950 during which the different organizational arrangements for Executive Office science advice have contributed with varying degrees of success to coordination, oversight, and planning. While scholarly literature supports the cut-off points between the periods that we have chosen, these points are a matter of interpretation. We describe these periods below, and illustrate significant developments influencing science policy in figure 4.1.

Figure 4.1: Key Periods and Events Affecting U.S. Science Policy Advisory Organizations Since 1950

Science Advice Focuses Primarily on Military Issues

1950 National Science Foundation established; William T. Golden memorandum to Truman suggesting Science Advisor and Science Advisory Committee.
1951 Truman creates Science Advisory Committee (SAC) in the Office of Defense Mobilization.
1952
1953
1954
1955
1956

More Centralized Science Advice Focuses on Broader Issues

1957 Soviets launch Sputnik 1, October 4; Eisenhower creates Office of Special Assistant to the President for Science and Technology, November 7; SAC changed to President's Science Advisory Committee (PSAC).
1958 Sen. Hubert Humphrey introduces bill for Department of Science and Technology.
1959 Eisenhower changes Interdepartmental Committee on Scientific Research and Development to Federal Council on Science and Technology (FCST).
1960
1961
1962 Kennedy creates Office of Science and Technology (OST); National Academy of Sciences sets up Committee on Government Relations (CGR).
1963 Academy changes CGR to Committee on Science and Public Policy (COSPUP).
1964 National Academy of Engineering established.

Influence of Central Structure Erodes under Less Supportive Presidents

1965
1966
1967
1968
1969
1970 Institute of Medicine established. Bureau of Budget becomes Office of Management and Budget.
1971
1972 Office of Technology Assessment established.
1973 Nixon abolishes OST and disbands PSAC.

Congress Debates Executive Office Science Advice and Passes Public Law 94-282

1974
1975
1976 Ford signs P.L. 94-282 establishing Office of Science and Technology Policy (OSTP), President's Committee on Science and Technology (PCST); FCST becomes Federal Coordinating Council on Science, Engineering and Technology (FCCSET).

Structure for Executive Office Science Advice Remains Essentially the Same Since 1976

1977
1978 Carter abolishes PCST.
1979
1980 OSTP issues report discouraging a Department of Science and Technology.
1981 COSPUP becomes Committee on Science, Engineering, and Public Policy (COSEPUP).
1982 White House Science Council set up by OSTP Director George Keyworth II.
1983
1984 National Academies begin Government-University-Industry Research Roundtable.
1985 Report of the President's Commission on Industrial Competitiveness recommends Department of Science and Technology.
1986

1950 to 1957 (Pre-Sputnik): Science Advice Focused Primarily on Military Issues

From 1950 until 1957, the type of advice the President received on science and technology issues came from diverse sources and did not comprehensively address the science and engineering base. It was primarily related to military strategy and weapons systems. Several organizations provided this advice, including the Interdepartmental Committee on Scientific Research and Development (an interagency coordinating committee established in 1947) and the Science Advisory Committee, established in 1951. The Science Advisory Committee was located within the Office of Defense Mobilization; there was no central structure for presidential science advice within the White House. The National Science Board was established in 1950 with a broad charter which included responsibility for developing national policies for basic research and science education and evaluating federal research programs. From its beginning, the Board focused mainly on overseeing the activities and programs of NSF, since it had no authority over other agencies and could be viewed as a competitor with other agencies for federal research funds.

1957 to Mid-1960's: More Centralized Science Advice Focused on Broader Issues

During the period immediately following the Soviet launching of Sputnik I until the end of the Kennedy/Johnson administration, a strong central science advisory committee advised the President on a wide range of issues affecting the science and engineering base; there was also a somewhat less effective interagency coordinating committee. Immediately after the shock of Sputnik in 1957, President Eisenhower took steps to centralize science advice by creating the Office of Special Assistant to the President for Science and Technology and reconstituting the Science Advisory Committee as the President's Science Advisory Committee (PSAC) within the Executive Office. He continued these centralizing efforts in 1959, replacing the interagency coordinating committee at a higher policy level with the Federal Council on Science and Technology (FCST). FCST was formally linked at this point to the Special Assistant to the President for Science and Technology and to PSAC.

PSAC was most influential with the Presidents during the early years of its existence. Under the Eisenhower and Kennedy administrations, PSAC enjoyed presidential support and worked effectively with the other key players in the science policy arena. It was able to provide independent advice to the President on a wide range of both military and nonmilitary issues. For example, PSAC examined and advised upon the development of a civilian space agency and science education in high schools, as well as on ballistic missile development and defense, arms reduction, and a nuclear test ban in the atmosphere, underwater, and outerspace. As described below, PSAC's influence declined after the early 1960's, when the Johnson and Nixon administrations were less supportive of it.

FCST replaced the Board in responsibility for federal R&D coordination and policy development (other than for basic research and science education) but was not successful in resolving controversial "turf" issues among the agencies. Throughout its history, FCST was most effective in gathering information and developing program inventories. It also was relatively successful in coordinating administrative policies and practices for R&D in the agencies and in identifying needs for increased R&D in selected areas, but has been criticized for an inability to deal with controversial issues that would affect the individual interests of the various mission agencies.

Reorganization Plan of 1962 Established the First Central Science Office at Presidential Level

President Kennedy's Reorganization Plan No. 2 of 1962 established the Office of Science and Technology within the Executive Office. The plan linked PSAC and FCST to the new office and marked the first time that a central science advisory organization was established at the presidential level. The plan was a precedent for the current organizational arrangement. Directed by the Special Assistant for Science and Technology, who also customarily chaired PSAC and FCST, the office's mandate gave it broad responsibilities in coordinating, overseeing, and planning the nation's science and engineering activities. It was intended that the office

- advise and assist the President with respect to the relation of federal science and technology policies to other national policies, especially national security and foreign relations policies;
- advise on ways to further U.S. science and technology;
- assess scientific and technical developments;
- evaluate and coordinate federal science and technology efforts; and
- advance relations between the federal government and the scientific and engineering communities.

The Office of Science and Technology Assumed the National Science Board's Responsibilities for Evaluating and Coordinating Federal Science Activities

The reorganization plan transferred to the Office of Science and Technology the evaluation and coordination responsibilities for basic research and science education that the Board had retained after FCST was established. This reflected congressional and Bureau of the Budget perceptions that NSF, as a small agency with a mission to support basic research and education in the sciences, could not successfully coordinate and evaluate scientific and technical activities over the wide spectrum of government.

Mid-1960's to 1973: Influence of Central Structure Eroded Under Less Supportive Presidents

From the mid-1960's until President Nixon abolished the Office of Science and Technology and PSAC in 1973, the Executive Office science advisory structure gradually decreased in influence and importance with the President. This development was attributable to a number of factors, two important ones being the growing perception within the White House that the Office of Science and Technology was a "special interest" group representing the scientific community and that members of PSAC could not be relied on to support presidential policy.

This period also evidenced a growing realization that, unless controlled, some of the results of rapidly developing new technologies had negative repercussions. PSAC studies increasingly explored environmental and health issues related to scientific and technological developments. During this period, the Congress initiated legislation creating OTA and, in 1972, the bill was signed into law.

During the Johnson and Nixon administrations, PSAC's influence gradually declined, as the committee's task of providing science advice in the context of socioeconomic and political concerns became increasingly complex and presidential interest and support waned. Meanwhile, as basic research budgets continued to grow while the total federal R&D outlays increased only slightly, PSAC began to be perceived in the White House as performing an advocacy role for basic science. This constrained PSAC's ability to work effectively with other White House staff and the Bureau of the Budget. President Nixon became disenchanted with the roles of the committee and the Office of Science and Technology and, with Reorganization Plan No. 1 of 1973, he abolished them. This plan transferred all responsibilities vested in the Office of Science and Technology to the Director of NSF and also made him Science Advisor to the President. The Director of NSF served in this dual capacity until Public Law 94-282, which established the current organizational arrangement, became law in 1976.

1973 to 1976: The Congress Debates Executive Office Science Advice and Passes Public Law 94-282

After the Office of Science and Technology and PSAC were abolished, the House Science and Technology Committee held extensive hearings and initiated legislation to reestablish a central science advisory structure within the Executive Office. On May 11, 1976, President Gerald Ford signed the legislation entitled the National Science and Technology Policy, Organization, and Priorities Act of 1976 (Public Law 94-282)

> ". . . to establish a science and technology policy for the United States, to provide for scientific and technological advice and assistance to the President [and] to provide a comprehensive survey of ways and means for improving the federal effort in scientific research and information handling . . . ."

Public Law 94-282 established four interrelated components for Executive Office science advice. The umbrella organization was OSTP, directed by an individual who would also provide advice to the President on the scientific and technological aspects of issues requiring presidential attention. In establishing OSTP as a legislated body, the Congress minimized the risk of any President's eliminating this office in the way President Nixon had eliminated the Office of Science and Technology. The other three organizational components created in Public Law 94-282 were the Federal Coordinating Council for Science, Engineering, and Technology (FCCSET), which replaced FCST; the President's Committee on Science and Technology, a 2-year committee set up to survey federal science and engineering objectives, policies, programs, and organization; and the Intergovernmental Science, Engineering, and Technology Advisory Panel.[1]

Current Organizational Arrangement: Structure for Executive Office Science Advice Has Remained Essentially the Same Since 1976

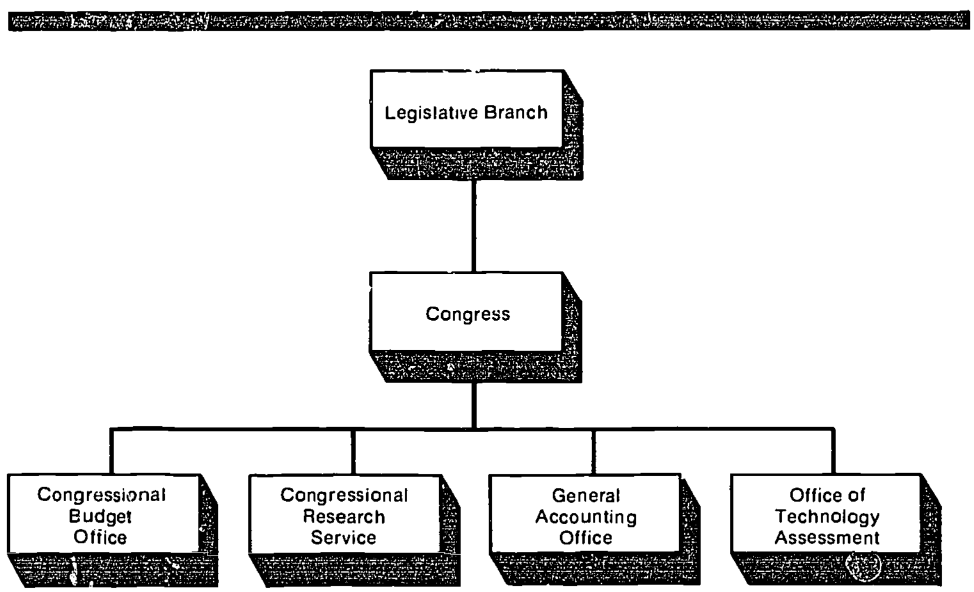
Currently, OSTP, the Board, and OMB in the executive branch; the congressional support agencies in the legislative branch; and the Academies as independent organizations perform important roles in the governance of the science and engineering base. OSTP has the most central role. This office has broad responsibilities, including coordination, oversight, and integrated strategic planning for the science and engineering base. Specifically, OSTP advises the President and the executive agencies on science and technology issues and their relation to national concerns, evaluates and helps to coordinate federal science and technology efforts, and assists the Office of Management and Budget with an annual review

[1] The Intergovernmental Science, Engineering, and Technology Advisory Panel was established to (1) identify and define civilian problems at state, regional, and local levels which science, engineering, and technology could assist in resolving or ameliorating, (2) recommend priorities for addressing such problems, and (3) facilitate the transfer and utilization of research and development results to meet civilian needs. Inasmuch as the scope of this study is limited to the federal policy role for the science and engineering base, we do not discuss the role of the panel.

and analysis of proposed federal funding of research and development. As overseer of NSF, the Board is responsible for encouraging the pursuit of policies which advance research and education in science and engineering. OMB's role in governing the science and engineering base is primarily by virtue of its central position in the preparation of the federal budget and by providing guidance to all agencies for implementing legislative regulations, executive orders, and administrative procedures relating to accountability. Figure 4.2 illustrates the official organizational arrangement for science advice to the executive branch.

On the legislative side, OTA, GAO, CRS, and the Congressional Budget Office provide information to the Congress for its oversight of the science and engineering base. Finally, as independent organizations chartered by the federal government, the Academies conduct studies and provide information and advice to the federal agencies, OSTP, the Congress, and the public on a wide range of science, engineering, education, environmental, and health-related issues.

Figure 4.2: Official Organizational Arrangement for Science Advice to the Executive Branch



OSTP Is the Central Focus in the Executive Branch

The Executive Office science advisory organization includes two of the four components legislated in Public Law 94-282, as well as a science council that advises the Director. President Carter abolished the President's Committee on Science and Technology by Executive Order 12039, and President Reagan abolished the Intergovernmental Science, Engineering, and Technology Advisory Panel by Executive Order 12399. George Keyworth II, President Reagan's Science Advisor, established the White House Science Council (WHSC) to advise OSTP in February 1982.

President Carter did not appoint a Science Advisor and Director of OSTP until mid-March 1977, after important R&D budget decisions had been made. This caused concern within the science community. After assuming the role of Presidential Science Advisor, however, Frank Press established effective working relationships with the President, White House staff, and OMB. He was credited with the Carter administration's strong support of basic research and also helped formulate policies for organizational reform, technological innovation, and environmental protection, among other areas.

President Reagan delayed the appointment of Mr. Keyworth as Presidential Science Advisor until approximately 6 months into his first term of office, after important R&D budget decisions had been made and most presidential appointees for top federal government positions had been selected. Nonetheless, during President Reagan's first term in office, basic research experienced its greatest growth in many years. As Science Advisor and Director of OSTP, Mr. Keyworth advocated continued expansion of federal support for basic research (which has continued under the current administration) and helped to initiate the establishment of national engineering research centers.

Under the current administration, OSTP's position within the Executive Office has been downgraded. After the departure of Edwin Meese as Counsellor to the President, the access of OSTP's Director to the President was curtailed. In June 1986, a former staffperson at OSTP told us that OSTP has little influence with agency heads in affecting research budgets. A high-level OMB official we interviewed in June 1986 said that scientists are rarely in the President's inner circle for setting policy, implying that OSTP has little influence within the White House.

OSTP's Mandate Includes Integrated Strategic Planning

Like the Office of Science and Technology before it, OSTP has broad coordination, oversight, and planning responsibilities and is also expected to conduct integrated strategic planning in the sense we defined it in chapter 1—to include analyses of cross-cutting interagency issues and foresight to identify emerging issues and analyze potential long-term impacts of current decisions. Title I of Public Law 94-282 includes the following statements:

"To implement the policy enunciated in [this Act], . . . (1) The Federal Government should maintain central policy planning elements in the Executive Branch which assist Federal Agencies in (a) identifying public problems and objectives, (b) mobilizing scientific and technological resources for essential national programs, (c) securing appropriate funding for programs so identified, (d) anticipating future concerns to which science and technology can contribute and devising strategies for the conduct of science and technology for such purposes, [and] (e) reviewing systematically Federal science policy and programs and recommending legislative amendment thereof when needed.

Comprehensive legislative support for the national science and technology effort requires that the Congress be regularly informed of . . . the relation of science and technology to changing national goals . . . ."

FCCSET Is OSTP's Coordinating Body

FCCSET is the central coordinating body for federal science and engineering activities. Composed of the Director of OSTP and a representative from each of the major research agencies, FCCSET has a legislative mandate to examine problems and developments in the fields of science, engineering, and technology affecting more than one federal agency. Its responsibilities include

- recommending planning policies,
- identifying research needs, and
- achieving more effective use of science and engineering resources at federal agencies.

FCCSET's composition, role, and apparent limitations are very similar to those of its predecessor, FCST. Within FCCSET, committees are organized by topical areas. While we were not able to assess fully FCCSET's effectiveness in coordinating federal science policy, we have not seen evidence under the current administration that the Director of OSTP has enough influence with agency heads to reconcile conflicting views on cross-agency issues. The former Director of OSTP under President Carter, however, told us in July 1986 that he believes FCCSET could influence research agency budgets, provided its Chairman (the Director of OSTP) establishes effective working relationships with OMB. This would also require strong presidential support.

WHSC Is the Primary Advisory Body to OSTP

Mr. Keyworth, former Science Advisor to President Reagan and Director, Office of Science and Technology Policy, established the White House Science Council on February 16, 1982, to ". . . advise the Director . . . and keep him informed of changing perspectives in the science and technology communities." WHSC's agenda is set by the Director of OSTP.

WHSC differs from the former President's Science Advisory Committee (1957-73) in that the council itself has no direct access to the President (although two WHSC members who have long-term friendships with the President do meet with him occasionally). WHSC members are appointed by the Science Advisor, report to him, and deal with topics assigned by him. One high-level authority at the Academies told us that WHSC studies are effectively used at the agency level to help justify and lend status and authority to policy initiatives.

OSTP Coordinates, Oversees, and Plans for Science and Technology by Topical Areas

Coordination

Through FCCSET and ad-hoc interagency committees, OSTP studies and reports on issues and opportunities in specific topical areas but generally does not address the crosscutting issues among the fields of science and engineering. The reports issued by FCCSET and WHSC frequently include recommendations for strengthening coordination among federal agencies in the particular area they address (for example, Report of the Federal Coordinating Council on Science, Engineering, and Technology Panel on Advanced Computer Research in the Federal Government, June 1985, and WHSC's report, Research in Very High Performance Computing, November, 1985).

A WHSC panel study on federal science coordination ongoing in November 1986 is another example of an OSTP activity to improve coordination. A staff person at OSTP informed us that two likely recommendations of this panel would be that the Director of OSTP be given Cabinet-level status and FCCSET be composed of higher level agency representatives.

Oversight

In its oversight capacity, OSTP reviews some or all of the research agencies' budgets before they go to OMB and (in part through FCCSET and WHSC reports) recommends policy actions throughout the year by topical areas. In a September 1986 interview, the Executive Director of OSTP told us that while OSTP attempts to review all research agency budgets and provide advice and recommendations to both OMB and the agencies, OSTP does not, in practice, have the authority or the responsibility in the budget-making process that was intended in Public Law 94-282. Others informed us that OSTP's impact on the research budget occurs mainly through staff-to-staff interactions between OSTP personnel and other key players in the White House and OMB.

Integrated Strategic Planning

OSTP has never established a structure to conduct integrated strategic planning for the science and engineering base. Our September 1980 report on OSTP stated that OSTP attempted to give a strategic perspective to considerations of topical or mission issues but believed it was not feasible to do more comprehensive strategic planning, given the resources available to it and the high-pressure environment within the Executive Office of the President. In April 1986, an OSTP staff person informed us that OSTP views long-range horizon scanning as part of its mission, but that the office has no formal structure in place to do this. An official at OSTP told us in September 1986 that he had suggested to the Science Advisor in 1982 that a Special Studies Office be established within OSTP, with personnel to conduct comprehensive strategic planning. The official told us that no resources were established for such an office and that while Science Advisor Keyworth was supportive of his suggestion, the office then as now has had to devote its resources to "firefighting" and has not had the time or personnel for such an effort.

Notwithstanding the lack of integrated strategic planning at OSTP, a number of the FCCSET and WHSC ad-hoc topical studies appear to contribute to planning in certain fairly broad topical areas. For example, WHSC's November 1985 report, Research in Very High Performance Computing recommends the establishment of cross-disciplinary research programs. Other broadbased efforts to improve planning that would affect important segments of the research base are illustrated in Report of the White House Science Council Federal Laboratory Review Panel, May 1983, and Report of the White House Science Council Panel on the Health of U.S. Colleges and Universities, February 1986.

Other Executive Branch Organizations Contribute to Governance of Science and Engineering Base

In addition to OSTP, the Board and OMB also play important roles within the executive branch in overseeing research and helping to determine research priorities.

The National Science Board Focuses on NSF

The Board is the governing body of NSF. The Board is composed of 24 members appointed by the President for staggered 6-year terms, and the Director of NSF. Members are selected for their distinguished service in science, engineering, education, industry, research management, public affairs, medicine, and agriculture; they represent all areas of the nation. The principal role of the Board is to oversee NSF's operations and establish policies for NSF to fulfill its various statutory missions. The Board also has legislated responsibilities to assist in the formulation of national science policies.

Historically, the Board has not enunciated or assumed the lead in developing governmentwide policies for the science and engineering base nor sought to coordinate federal agency programs or policies that affect the base. The Board's oversight has consisted mainly of providing guidance and assistance to NSF on its programs, plans, and policies. Occasionally, the Board sponsors selected studies and reports on science policy issues germane to NSF but also relevant to support of research and education by other agencies. These studies and the Board's task forces often address how NSF programs can help to resolve a particular research problem that extends beyond the purview of NSF. The Board's planning activities are also focused on NSF's programs.

Over the years, the Board has continued to discuss its role in policymaking for the nation's science and engineering base. In December 1980, the Board commissioned a study of its policy responsibilities so that the Board could examine the appropriateness and practicality of strengthening its policymaking activities, especially on issues extending beyond NSF's own programs. The study's results were presented to the Chairman on July 31, 1981, in a report entitled The National Science Board and the Formulation of National Science Policy. In his concluding observations, the report's author cautiously encouraged the Board to move into a larger role in national science and technology policy leadership, provided that: the Director of NSF exercised strong managerial responsibilities over NSF (thereby freeing the Board to examine issues beyong NSF); the Board's regular working operations were restructured so as to permit more deliberative activity by the Board on policy issues; the Board was highly selective in its choice of policymaking issues; and the Board obtained additional staff support. In response to this study, the Board concluded in September 1981 that the statutory responsibilities provided by the Congress gave ample scope for the Board to engage in policy matters beyong the oversight of NSF operations and program priorities. Since this time, the Board has continued occasionally to discuss the issues raised in this study but has not issued any written statements or plans on the desirability or feasibility of the Board taking on policymaking responsibilities beyond the purview of NSF.

Neither the present Board Chairman nor the Director of NSF has confidence in the effectiveness of the Board's attempting to advise OSTP or the agencies. The Chairman of the Board told us in June 1986 that he believes that the Board could realistically influence broader areas of the science and engineering base only if NSF were explicitly assigned a greater management and budget authority by the President. In a similar vein, the Director of NSF indicated to us in August 1986 that it would be essential for NSF to have a larger direct responsibility for supporting basic research and education in the sciences than it does now in order to have more influence over policies for the science and engineering base.

The Office of Management and Budget Influences Research Priorities by Preparing the Federal Budget

By virtue of its actions in the budget process and stature within the Executive Office of the President, OMB makes decisions that affect science and technology programs. OMB can discourage or reduce budget allocations for some programs while using budget leverage to foster new initiatives in those R&D areas it believes to be underfunded. For example, officials at OMB told us that they use NSF to adjust research to support areas (e.g., research instrumentation, ground-based solar astronomy systems) that they perceive to be underfunded by other agencies. In addition, the officials said that OMB monitors R&D programs and informally coordinates scientific and technological activities. This involvement and the fact that most action resulting from strategic planning or coordination would be implemented through OMB's role in the budget process make OMB an important player. Although OMB is the one place where the agencies' separate budgets come together in a comprehensive federal budget, R&D is not treated as a whole within OMB. Staff members in different divisions examine different portions of the R&D budget. For example, health and defense R&D programs are not reviewed by the budget examiners who handle space, energy, and other sciences.

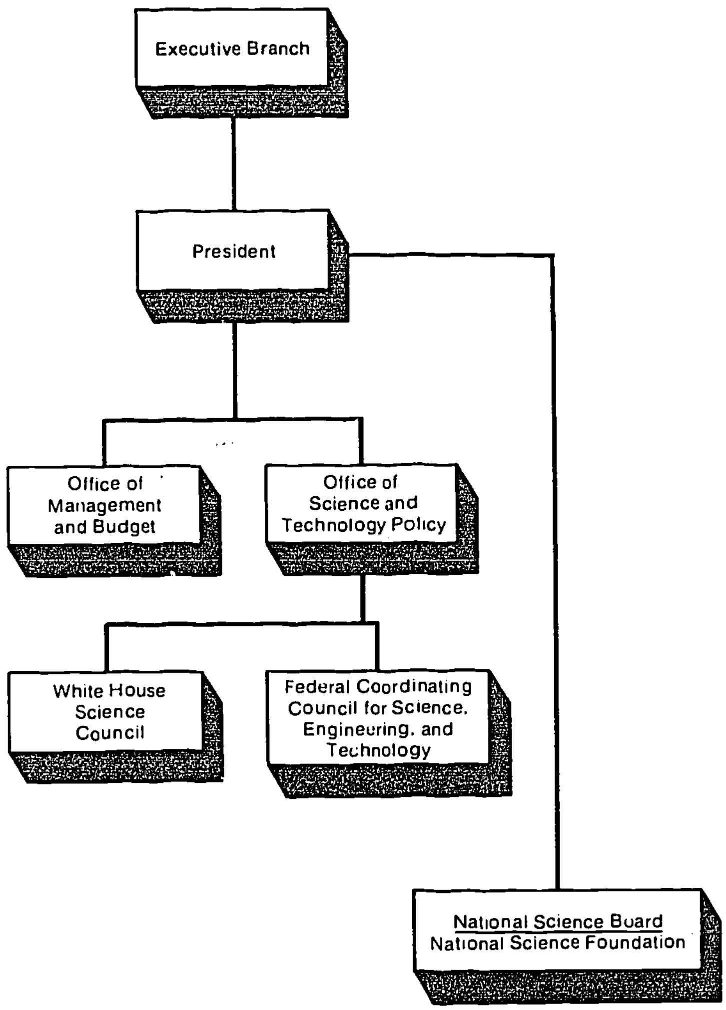
Other than its budgetary role described in chapter 2, OMB's Special Analysis for R&D essentially summarizes the administration's changes in R&D from the previous year in relation to private sector funding and the rationale for continuing the same general strategy and/or shifting priorities among agencies and programs, such as the emphasis on basic research.

The OMB staff we interviewed believe that, for the most part, agencies are responsible for budgetary planning. The staff members stated that OMB generally does not interact with the planning process in its early stages other than by giving general number ceilings to the agencies in an annual allowance letter; agencies do their own planning and review their plans internally. Although OMB has increased its scientific and engineering staff resources over the years, its role in R&D planning and priority determinations is still primarily based on information received from agencies, on advisory assistance from OSTP, and on the incumbent President's agenda.

Legislative Branch Organizations Assist the Congress in Evaluating Executive Branch Initiatives

The Executive Office of the President takes the lead in setting science policy, while the Congress plays an important role primarily by reacting to presidential initiatives and passing legislation that affects the science and engineering base. The Congress is assisted by four support agencies. As shown in figure 4.3, they include OTA, GAO, CRS, and the Congressional Budget Office.

Figure 4.3: Congressional Support Agencies



Office of Technology Assessment

The creation of OTA in 1972 marked the first time that a science and technology advisory office was established to report exclusively to the Congress. The Technology Assessment Act of 1972 established OTA "... to provide early indications of the probable beneficial and adverse impacts of the applications of technology and to develop other coordinate information which may assist the Congress" (Public Law 92-484, Section 3c).

OTA's activities are influenced by both parties of the Congress. The Technology Assessment Board, which governs OTA, is bipartisan with six members each from the House and Senate, while OTA's Advisory Council is composed of GAO's Comptroller General, the Director of CRS, and private citizens appointed by the Technology Assessment Board. In conducting its studies, OTA convenes panels of high-level experts and interested citizens from a variety of perspectives and also engages private contractors and consultants.

General Accounting Office

GAO evaluates agency program and management performance in relation to statutory requirements, presidential directives, OMB guidelines and agency plans. When involved in complex and sophisticated science and technology issues, GAO may supplement its internal staff expertise with outside consultants. In addition to evaluating agency-sponsored R&D programs by GAO divisions responsible for oversight of mission agencies, a multidisciplinary group within the Resources, Community, and Economic Development Division performs a variety of governmentwide science and technology policy evaluations. In R&D budgetary issues, this group collaborates with other GAO groups involved in budget reform studies.

Congressional Research Service

CRS is responsible for providing the Congress with information on any subject in which the Congress is interested. Within the time and resources it has available, CRS contributes to the foresight needs of the Congress by providing information, research, and analysis on critical national global trends and issues that require congressional attention.

Congressional Budget Office

The Congressional Budget Office, while created mainly to collect, process, and analyze budget-related information, also produces informative reports on the federal role in supporting research and development.

The Academies Are Independent Organizations That Advise the Federal Government

The Academies include the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine, as well as two operating units, the National Research Council, and the Committee on Science, Engineering, and Public Policy. As independent organizations chartered by the federal government, their institutional role in coordination, oversight, and planning for the science and engineering base is by virtue of the studies they conduct. Inasmuch as the Academies have a historical reputation for scholarly advice and access to a vast pool of experts, they are an important resource available to the federal government. Many members of top-level government advisory committees have been nominated or suggested by the Academies.

The Academies Are Broadening Their Treatment of Science and Technology Issues

In the past, the Academies have been criticized for focusing too narrowly on the technical aspects of specific issues, but it now appears that the Academies are striving to deal with more far-ranging topics in their political contexts. For example, Philip M. Boffey, who investigated the Academies from 1971-73 for Ralph Nader's Center for Study of Responsive Law suggested in his 1975 book, The Brain Bank of America, that the Academies were limited in their ability to perform studies beyond narrowly defined technical or scientific issues. One possible reason for the limited scope of some assignments may have been that most tasks were performed in response to requests from federal sponsors who reimbursed the Academies only for costs incurred in performing the requested work. In congressional testimony on May 8, 1986, however, Frank Press, President of the National Academy of Sciences, suggested that the Academies are increasingly producing more broad-based, policy-oriented reports. He reported that the approximately 300 reports that the Academies issued in 1985 addressed topics that covered a wide range of congressional concerns. His view was confirmed by statements by the Presidents of the National Academy of Engineering and the Institute of Medicine.

Recently, the Academies have begun to establish discretionary funds from other sources which provide seed money to survey and plan for anticipated federal requests and in some cases to initiate projects independently, which the Academies believe may yield significant results for use by the federal government and the public.

Possible Changes to Current Organizational Arrangement

OSTP, the Board, OMB, the congressional support agencies and the Academies all contribute to the governance of the science and engineering base, but no organization conducts integrated strategic planning. Policy-level coordination and oversight activities occur by topical areas. Responsibility for these functions is legislatively assigned to OSTP, but this office has no arrangement for conducting integrated strategic planning and instead coordinates and oversees the science and technology activities by topical areas.

This section discusses several organizational changes which could be used to revise interagency coordination, oversight, and planning. The changes are not exhaustive but illustrate a range of possible changes that could be made within the existing organizational framework.

Elevate the Stature and Authority of OSTP

As mentioned in chapter 1, the science and engineering base undergirds many national needs, including industrial competitiveness. A strong consensus is developing among leaders in the Congress, the executive branch, and the private sector that the need to strengthen U.S. industrial competitiveness is a major issue although there is not agreement about what steps should be taken to solve the problem. Currently, the Reagan administration is developing a strategy for strengthening U.S. industrial competitiveness. Two objectives of President Reagan's competitiveness program would involve components of the science and engineering base. These objectives are to refocus educational priorities on science education and increase federal funding of basic research. In the Congress, members from both parties and houses have established the Congressional Caucus on Competitiveness to focus on competitiveness from the legislative perspective.

Given its legislated mandate, OSTP is responsible for providing advice to the President on the scientific and technological aspects of issues directly related to our scientific and technological competitiveness. Recognizing the important contribution of a strong science and engineering base to competitiveness, the President could direct OSTP to take the lead in developing long-term policies for those aspects of industrial competitiveness that depend on a strong science and engineering base.

Historically, the effectiveness of the executive office science advisory mechanism has depended to a large extent on the degree of presidential interest and support it has received. Without a clear directive from the President, OSTP has had no direct authority over decisions made by the federal research agencies or OMB. Thus, OSTP has been limited in its ability to develop long-range science and engineering policy, coordinate federal science and engineering efforts and maximize these resources' contribution to meeting national needs.

Recognizing that OSTP's position within the White House and with respect to OMB and the research agencies is a matter of presidential discretion, the Congress could nonetheless pass a joint resolution reiterating its expectations expressed in Public Law 94-282 that the Director of OSTP have access to the President and have a strong leadership role with respect to OMB and the federal agencies in determining budget priorities, developing policy, and overseeing federal research.

Presidents Eisenhower and Kennedy conveyed the title "Special Assistant to the President for Science and Technology" to the science advisor. This title symbolized to the White House staff, Bureau of the Budget, and cabinet-level agencies that the science advisor had the President's ear and that he was authorized to act for the President in science policy matters. In its joint resolution, the Congress could encourage the President to provide the Science Advisor with a title such as "Special Assistant to the President for Science and Technology." The President could give the Special Assistant final authority over federal resource allocation decisions affecting the science and engineering base and a strong advisory role with respect to other federal agency R&D decisions. The President could also direct OSTP specifically to develop long-range plans and policies for the science and engineering base, policies essential to rebuilding the nation's industrial competitiveness.

Create a Presidential Science Advisory Committee

The President could, either as part of a strategy to strengthen OSTP or as a separate action, consider reviving a broad-based science advisory committee, similar to the President's Science Advisory Committee, which existed from 1957 to 1973. The committee would be chaired by the Director of OSTP, who would report directly to the President. The objective of this alternative would be to broaden the advisory resources available to OSTP, providing the President with a committee of top-level science policy advisors from a wide range of disciplines. The committee would contribute to coordination, oversight, and integrated strategic planning for the science and engineering base, and its chairman would advise the President on longer term, often interagency science and engineering issues in their scientific as well as political, socioeconomic, and other dimensions. The committee could need staff support to carry out its functions, including following up on its suggestions. One resource for this support could be OSTP staff.

OSTP Could Establish Formal Means for Integrated Strategic Planning

Public Law 94-282 intends for OSTP to conduct comprehensive strategic planning for the national science and technology effort, yet OSTP has no formal structure in place for conducting such planning and is limited by its tight staff resources and the need to respond to day-to-day pressures. Our 1980 report The Office of Science and Technology Policy: Adaptation to a President's Operating Style May Conflict with Congressionally Mandated Assignments (PAD-80-79, Sept. 25, 1979), recommended that OSTP's Director establish such a mechanism.

An OSTP staff group with explicit responsibility to conduct integrated strategic planning could identify emerging issues, evaluate potential consequences of today's decisions, and prioritize research areas needing attention. The group could obtain assistance from sources outside of OSTP, including NSF and the Academies. The group also would need to work closely with the mission agencies to understand their concerns and obtain their assistance. This would help to ensure that the agencies are receptive and cooperative in implementing strategic planning initiatives.

Office of Technology Assessment Could Conduct Long-Range Analyses of Emerging Issues

While the focus for leadership in determining science policy is clearly placed within the Executive Office, the Congress could also consider an alternative to focus congressional attention on broad-based planning for and oversight of the science and engineering base.

Evaluation of the congressional role was not within the scope of our study, but a number of officials we interviewed pointed out that the multiple-committee structure of the Congress, in which many committees in the House and Senate have limited and sometimes overlapping jurisdictions, constrains the effectiveness of the Congress in dealing with issues that transcend individual agencies. By reorienting the focus of some of the information it requests from OTA, the Congress could analyze strategic policy options for the entire science and engineering base.

OTA's principal legislative mandate is ". . . to provide early indications of the probable beneficial and adverse impacts of the applications of technology and to develop other coordinate information which may assist the Congress."

A recent OTA initiative could facilitate increased attention to longer range, more integrated analyses of strategic policy options. Since 1983 OTA has explicitly broadened its treatment of science and engineering issues. According to OTA's 1985-86 program charter for its Science, Education, and Transportation Program:

"Science as understood for the purposes of program development should include issues surrounding the 'health of the scientific enterprise.' These issues include the development and utilization of scientists, the decision process for allocation of Federal funds for basic research, dissemination of and access to scientific information and data, the role of federal and other institutions designed to support or regulate research, and the theory and practice of research and development."

Thus, the Congress could ask OTA to analyze future impacts of strategic policy initiatives and plans. The information provided by OTA would transcend the boundaries of the various congressional committees, thereby providing an integrating factor for congressional focus on broad-based coordination, oversight, and long-range strategic planning for the science and engineering base.

The Academies Could Help OSTP (and the Congress) Develop Strategic Policy Options

With more flexibility in federally commissioned work and increased funds from independent sources, the Academies could provide OSTP (and the Congress) with broad-based, long-range studies that analyze and assess trends, issues, and opportunities affecting the science and engineering base. The Academies would be especially well-suited to this task, given their independent position vis-a-vis the federal government, access to a wide range of expertise, and expanding treatment of research issues in their political contexts. In performing this work, the Academies could draw upon their own staff resources as well as the Government-University-Industry Research Roundtable. The Research Roundtable has proved to be an effective forum for debating issues and alternatives related to the science and engineering base. OSTP (and the Congress) could use the information the Academies would provide to develop strategic policy options for the science and engineering base.

In all, we are suggesting five possible changes to the current organizational arrangement. These changes are neither exhaustive nor mutually exclusive; several or all of them could be made at the same time. The first three address presidential support, the critical factor that historically has influenced the effectiveness of Executive Office science advisory mechanisms. The fourth change focuses on strengthening Congress' ability to analyze strategic policy options based on the information it requests from its support agencies, especially OTA. The fifth change describes how the Congress and the Executive Office could make greater use of the resources of the Academies as an advisory resource for integrated strategic planning for the science and engineering base.

Perennial Policy Issues Affecting the Science and Engineering Base

We have developed a list of recurring policy issues germane to the federal role in overseeing and developing strategic policy for the science and engineering base. These issues are how to

- achieve long-range holistic planning and a coherent strategy for federal investment in basic and generic applied research without compromising the advantages of our pluralistic system;
- develop and apply more rational criteria for resource allocation among fields of science (and engineering), federal agencies, and research performers;
- improve the stability of research funding over a period of years while maintaining adequate flexibility to accommodate major changes in needs and opportunities;
- achieve a better balance between accountability for use of public funds and freedom of inquiry by researchers and universities on federally sponsored research;
- improve central oversight of the U.S. science and engineering base by both executive and congressional branches of the federal government;
- improve the quality, timeliness, and relevance of information needed by policymakers concerned about the U.S. science and engineering base;
- develop and consistently apply better measures or indicators of the status and direction of U.S. science and technology;
- determine and maintain an appropriate balance between federally funded research oriented toward providing a science and engineering base for private commercial applications and national government programs, e.g., national security, space, nationwide social goals, and international relations;
- achieve closer collaboration in research and science and engineering education among federal laboratories, universities, and technology-intensive industrial research centers;
- enhance the transfer and utilization of research results to foster technological innovation for public and private sector uses;
- decide appropriate respective roles of the federal, state, and local governments and the private sector in science, engineering, and mathematics education; and
- better integrate national science and technology policy with U.S. objectives and strategies in international affairs.

Similar Questions and Considerations Are Involved in Federal and Industrial Decisions Regarding R&D Funding

The kinds of questions and considerations regarding research and development funding faced by large, technology-intensive firms and the federal government are similar in several respects. For example, many of these firms do not distinguish between basic research and exploratory applied research, but they do separate corporate-sponsored research (whether they call it generic, pioneering, general, exploratory, or fundamental research) from shorter term product and process R&D supported by company divisions engaged in product manufacturing and engineering services. Corporate research is based on long-term investment strategy, and usually is small, for example, less than 10 percent of total company sponsored R&D. Hence, it tends to be insulated from fluctuations in the economy and the short-term variations in the marketplace. Product and process R&D supported by operating divisions are more likely to vary from year to year, depending on the projected sales outlook and the competitive market position of the sponsoring division.

High-technology corporations face such questions as follows:

- What is the appropriate level of corporate investment in long-range fundamental research, for example, in central laboratories and other selected research centers, both within and outside the company?
- How should criteria differ for decisions regarding corporate-sponsored, long-range research and R&D essential to product technologies in operating divisions?
- To what extent and how can stability and continuity of support for fundamental corporate research be maintained during periods of recession in company sales and profits?
- What criteria should be used to allocate resources among fields of investigation that are not commensurable?
- What factors should be considered in deciding whether to support fundamental research within the company or externally?
- Under what conditions should research efforts in particular areas be reduced or phased out completely?

Industrial decisions about allocating corporate research resources among fields of investigation are to a large extent subjective and may include the following considerations:

- Adequacy of the company's science and engineering base for each technology-intensive manufacturing and service business in which the company is or expects to be engaged.
- Pertinence to changing product technologies—problems and options.

- "Critical mass" for hot pursuit of emerging generic technology vital to the company's competitive edge and potential diversification.
- Availability of qualified research staff and essential facilities (either within or outside the company).
- Relative capital intensity and costs of special facilities and instrumentation.
- Time frame and total investment anticipated before tangible results worthy of the investment are likely to be achieved.
- Degree of risk versus certainty of success in relation to potential value of results, i.e., high risk/high payoff versus conservative research in more conventional directions.
- High-quality research effort in selected areas to monitor and evaluate scientific developments external to the company, i.e., credible expertise and stature to couple into the scientific community and recognize emerging opportunities to achieve early company leadership in technological innovation.
- University partnerships to complement research in company laboratories and to explore promising scientific opportunities before investing in permanent research facilities and staff.
- Possible acquisition of smaller R&D firms to expedite innovation in selected areas.
- Joint ventures with other firms (within antitrust constraints) to support fundamental research of mutual interest.
- Foresight, including analysis of trends and forces external to the company, that may have future impact on the economic outlook, competition in the marketplace, long-term profitability, and return on investment.

The federal government's objectives in supporting fundamental research obviously are broader than those of the private sector, which seeks primarily to enhance company growth, competitiveness, and financial return on investment. The federal government is concerned not only with industrial growth and competitiveness, but also with national security and international relations, human health and safety, environmental protection, and a number of other needs. Thus, the federal government's objectives in supporting fundamental research and science/engineering education have many dimensions.

Many, if not all, federal programs have economic dimensions. It, therefore, seems appropriate to compare federal govenment and industrial considerations involved in decisions about allocating fundamental research funds among fields of investigation. However, this comparison is not intended to imply that the federal government should adopt any industrial approach per se, but rather to suggest that there are facets of industrial planning and budgeting for corporate research that are adaptable to the federal approach in planning and budgeting for fundamental research.

Federal government decisions for allocating fundamental research funds among fields of investigation are to a large extent subjective and may include the following considerations:

- Adequacy of the U.S. science and engineering base for each national objective involving science and technology.
- Pertinence to the changing technology environment—needs and emerging opportunities.
- "Critical mass" for hot pursuit of emerging generic technology vital to U.S. international competitive leadership.
- Availability of qualified research staff and essential facilities (either within or outside the government).
- Relative capital intensity and costs of special facilities and instrumentation.
- Time frame and total investment anticipated before tangible results worthy of the investment are likely to be achieved.
- Degree of risk versus certainty of success in relation to potential value of results, i.e., high risk/high payoff versus conservative research in more conventional directions.
- High-quality research efforts in selected areas to monitor and evaluate worldwide scientific developments, i.e., credible expertise and stature to couple into the international scientific community and recognize emerging opportunities to achieve early U.S. leadership in technological innovation.
- University partnerships to complement research in government laboratories and to explore promising scientific opportunities before investing in permanent government research facilities and staff.
- Possible establishment of new centers of excellence to expedite innovation in selected areas.
- Joint ventures with other nations to support fundamental research of mutual interest.
- Foresight, including analysis of trends and forces both within and external to the U.S. that may have future impact on the economic outlook, international competition, and long-term socioeconomic trends.

Proposed Creation of a Department of Science and Technology

To some, a national department of science and technology would address the perceived inadequacies of the federal pluralistic system for dealing with research and development. Over the years, there have been a variety of proposals to establish a cabinet-level department. The proposals have involved alternative organizational structures, ranging from combining several agencies and laboratories—e.g., NSF, the National Bureau of Standards, NIH, selected research centers of the Department of Commerce, the National Aeronautics and Space Administration, and the Department of Energy—to consolidating all nondefense, high-technology agencies and technical service agencies—such as the Patent Office and the National Technical Information Service—into a single department. Most of these proposals have not included Department of Defense laboratories or federal contract research centers.

The issue of creating a federal department for science and technology has reappeared a number of times.[1] Frequently, these proposals surfaced when technology-related events or trends caused general concern over the adequacy of the pluralistic system to maintain U.S. leadership and prestige in technology and science. For example, shortly after the Soviet launching of the first artificial satellite, Sputnik, in 1957, Senator Hubert Humphrey introduced a bill for the creation of a department of science. More recently, the President's Commission on Industrial Competitiveness in 1985 recommended the creation of a department of science and technology after it reviewed the waning competitiveness of U.S. industry.

Despite the perennial nature of these proposals and recommendations, a federal department has never been adopted. The idea has typically encountered stiff opposition, and studies have not been favorable to the idea. Pursuant to its enabling legislation, OSTP studied the feasibility of consolidating scientific and technological activities into a department. In 1980 OSTP published its negative conclusion that the possible gains from establishing a department of science and technology would not outweigh the disadvantages.

The reasons for centralizing scientific and technological activities into a department have typically been to bring together similar activities of government into one governmental unit so that the activities would be better coordinated—not dispersed, more efficient—not redundant, more

[1]Proposals for a department of science and technology or a similar institution have come under a variety of names, including Department of Science; National Institutes of Research and Advanced Studies; Department of Research and Technology Operations; and Department of Science, Technology, Energy, and Materials.

coherent—not fragmented, and better planned—not sporadic. In addition, it has been argued that providing science and technology cabinet status would better science by placing science and technology advice closer to the decisionmaking process in the White House. However, as the arguments against such a department have time and time again prevailed, it appears evident that by centralizing, we would compromise the very diversity of opportunities that have made the American system effective. (A good source on the concept of a federal science department is "Special Issue: A Department of Science and Technology: In the National Interest?" in Technology in Society, Vol. 8, Nos. 1/2, 1986, with Frederick Seitz as guest editor.)

From the perspective of individual researchers, the U.S. system has been good. Having many agencies sponsor research gives a researcher the opportunity to apply to several places for sponsorship. This is good for the system as a whole because it gives a worthwhile project many chances for sponsorship, instead of just one.

Redundancy, it has been argued, is not necessarily a drawback to the current system. Science, by its very nature, needs to verify its results by other experiments. An underlying principle in science is that any properly designed experiment should be able to be replicated, attaining the same results.

Furthermore, much of the research sponsored by federal agencies is integral to their individual missions. Consequently, it is unlikely that these agencies, notwithstanding one or two possible exceptions, would support the creation of a department of science and technology. For example, it would be naive to expect to convince the Department of Defense to willingly relinquish control of its research.

Consideration of a major reorganization, such as a department of science and technology, is beyond the scope of this study. The case for and against this concept is included here for completeness and also to illustrate the perceived need for higher level attention and central leadership to supplement and alleviate perceived limitations of the existing decentralized, pluralistic system for supporting federal science and technology programs.

Arguments for and Against a Department of Science and Technology

The arguments for a department of science and technology address the problems of the current, "pluralistic" system and can be summarized as to

- better the coordination of research and development;
- have a more coherent and responsive science and technology policy, with long-range planning perspectives;
- give science and technology more visibility and elevated stature in the federal government and budget process;
- give science and technology cabinet status and presumably more direct access to the President;
- have an assured constituency and a department with which this constituency can be identified; and
- provide for effective oversight and allocation of scientific and technological resources.

For the most part, creating a department of science and technology has been disputed for the following reasons:

- R&D projects in departments and agencies are inseparable from agency responsibilities and missions, and the needs and emphasis of these differ from agency to agency.
- Science and technology activities flourish under diversity and competition.
- Full potentiality of science in government could be achieved only if it permeated the whole structure.
- To include R&D-related activities in one department would be unwieldy and difficult to manage.
- The increased budget of a department would make it politically vulnerable to budget cuts.
- Mission agencies might further retreat from supporting basic research.
- Given the modern day structure of the U.S. presidency with special assistants and the Executive Office, it is wrong to assume that a cabinet post would give science and technology more direct access to the President.
- Restructuring would be costly, and agencies and departments would most likely object to losing control of their R&D components.

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