

Dear Colleague:

The National Science Board draft discussion paper, "The Scientific Allocation of Scientific Resources," is being released for comment. This paper was prepared for the National Science Board by its Committee on Strategic Science and Engineering Policy Issues. It contains the preliminary recommendations from the committee's study on how priorities might best be set across fields and disciplines in the Federal budget for research.

Our study has addressed priority setting practices for publicly funded research, both in the U.S. and in other countries. We have commissioned two literature reviews, one by the RAND Science and Technology Policy Institute on the Federal system for funding research, existing tools to support research budget allocation decisions, and current mechanisms for input on those decisions. The second study, by SRI International, examined the literature on international models of S&T budget coordination and priority setting, focusing on eight governments, with presentations by top-ranking science officials for each in a public Symposium in November 1999. We also heard presentations from experts on specific methodologies proposed or in use to assist priority setting in research budgets.

The committee has met with representatives of OSTP, OMB, the National Academies, Congressional staff, and Federal departments and agencies who expressed considerable interest in improving the process by which funding decisions are made for federally supported research. We have arrived at some preliminary conclusions from these sources. Our draft recommendations focus on several areas for improved data, evaluation, and expert advice to achieve more effective priority setting for Federal S&T investments, including:

- Enhancements to the existing S&T policy apparatus in the White House to provide a continuing Federal capability for expert review, evaluation, and advice, representing a broad cross-section of the science and engineering research and education community, to inform decisions on research budget allocations;
- Better quantitative data and methods of analysis for evaluation of the effectiveness of Federal research support in achieving goals for research;
- A mechanism to identify and track the relevant Federal funds for S&T through the budget process in the Administration and Congress to support a coordinated Federal budget for research across agencies and departments.

We invite you as stakeholders in federally funded research to offer your comments on our preliminary findings and recommendations. You may submit your comments to the NSB Office by email to NSBOffice@nsf.gov, by mail to Jean Pomeroy, Room 1220, National Science Foundation, 4201 Wilson Blvd., Arlington, VA 22230; or by fax: 703-292-9008.

Sincerely,

Eamon M. Kelly, Chairman
National Science Board and
Committee on Strategic Science and
Engineering Policy Issues

DISCUSSION DRAFT FOR COMMENT

THE SCIENTIFIC ALLOCATION
OF
SCIENTIFIC RESOURCES

March 28, 2001

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I. INTRODUCTION

In the fifty years since the end of World War II and the establishment of a national policy for Government support of scientific research in colleges and universities, articulated by Vannevar Bush in *Science--The Endless Frontier*, historical trends and events have changed the public expectations for Federal research investments. The most important historical event affecting the national post-World War II consensus on Federal participation in science and technology is the end of the Cold War. Until that time, the rationale for Federal investments in research relied heavily on the contributions of science and technology to a strong national defense.

The last few Federal budget years have been favorable to research, but a favorable budget in one or two fiscal years does not obviate the need for a coherent post-Cold War Federal policy and decision process to guide investment in S&T. It is difficult to envision a reversal of the tide of accelerating competition among exploding scientific opportunities and between science and other worthy claimants on the budget. Today's environment demands more effective management of the Federal portfolio for research, including a sustained advisory process that incorporates systematic participation by the science and engineering communities. Expert input is particularly important for decisions on long-term, high-risk investments in research--sponsored mainly by the Federal government - which are steadily losing ground in the national research portfolio to short-term investments.

Box 1

"Yet, in holding scientific research and discovery in respect, as we should, we must also be alert to the equal and opposite danger that public policy could itself become the captive of a scientific technological elite. It is the task of statemanship to mold, to balance, and to integrate these and other forces, new and old, within the principles of our democratic system--ever aiming toward the supreme goals of our free society."

President Dwight D. Eisenhower, Farewell Address, 1/17/61

The Federal commitment to research over the last half century has contributed to a continuous outpouring of benefits to the public from advances in science and technology. Furthermore, within the last few decades these benefits have become increasingly visible and pervasive, from economic growth driven by high technology industries, to science and technology based transformations in many areas of public and private life--including, among others, the revolution in communications and information technologies, major medical breakthroughs, and superior defense technology demonstrated in the field. These underscore the value of sustained public investments reaching back decades. Moreover, even as the Federal share of funding has declined in national R&D, non-Federal sectors of the economy--industry, academe, state and non-profit--have come to rely on the Federal government to play a critical role in funding long-term investments in science and engineering discovery, education and innovation.

The success of the U.S. in encouraging the growth of its high technology industrial sector through public funding for science and engineering research and advanced education led to the U.S. system becoming a widely emulated international model. As

Federal Reserve Chairman Alan Greenspan noted: “. . . the research facilities of our universities are envied throughout the world . . . The payoffs in terms of the flow of expertise, new products, and start-up companies, have been impressive.” Nonetheless, recognition of the benefits of past public investments does not guarantee public support of the science and technology infrastructure necessary to enable future discoveries that may not yield measurable benefits for decades. Critics and supporters alike note the need for a clearly articulated and compelling rationale for Federal investments in science and technology equivalent in persuasive powers to the rationale of the Cold War.

II. NATIONAL POLICY CONCERNS AND NEEDS

Decision makers in the Executive and Legislative branches of government are concerned about the management of Federal investments in research, which in the most recent budget had reached over \$90 billion as measured by R&D. Articulating this concern, former OMB Director Franklin Raines in a 1998 Science article raised the following questions: How large a scientific enterprise does the United States need? How can we set priorities in the Nation's R&D enterprise? How can we measure the success of our Nation's research programs? How can we strengthen the government-university partnership? How do we engage the American people in the excitement and wonder of science?

Likewise, Chairman of the House Science Committee, Sherwood Boehlert, responded to the proposal to double Federal funding for research by questioning: "What are we going to get for that money? How will we know if we are under- or over-spending in any field?" He went on to warn: "I want the Committee, early on, to take a serious look at the balance within the federal research portfolio...You can ... count on me to ask tough and uncomfortable questions to ensure that the scientific community is acting in its and the nation's long term interest...We really need to push for more data". (1/21/2001).

How should the scientific community respond to these questions and expectations? How should it raise public awareness that the quality of life in the future will depend in large measure on the generation of new wealth, on safeguarding human health and the health of our planet, and on opportunities for enlightenment and individual development made possible by science and engineering discoveries? Will the response of the scientific community be effective against competing claims on the Federal budget?

These issues have prompted a vigorous policy debate over the last decade involving the Executive and the Legislature, the National Academies, and professional societies. Nonetheless, this debate has to this point generated no widely accepted process for the Federal government, with systematic input from the scientific community, to make priority decisions about the allocations in and across fields of research in support of Federal goals. The National Science Board has participated in this debate, issuing a series of policy statements, including an NSB working paper on Government Funding of Scientific Research in 1997. The NSB concluded in that paper that within the Federal budget there should be an overall strategy for research, with areas of increased and decreased emphasis and a level of funding adequate to both serve national priorities and to foster a world-class scientific and technical enterprise. To this end Congress and the Administration need to establish a process that examines the Federal research budget before the total Federal budget is disaggregated for consideration by Congressional committees. The Board further concluded in its 1998 Strategic Plan that a prerequisite for a coherent and comprehensive Federal allocation process for research is the development of an intellectually well founded and broadly accepted methodology for setting priorities across fields of science and engineering.

"A primary resource that would provide immediate benefits to decision makers is a broad-based, continuous capability for expert advice to both OMB and Congress during the budget allocation process."

As followup to its earlier work, the Board undertook, beginning in March 1999, a focused examination of Federal priority setting for research in the U.S. at three levels: 1) in setting Federal goals, 2) in allocation decisions by Congress and the Administration that produce the Federal portfolio for research and 3) in Federal agencies and departments in achieving their missions in alignment with stated Federal priorities. The Board determined that the appropriate level for its focus is the second level, that is, the White House and Congressional processes that in the aggregate produce the Federal portfolio of investments in research.

Context for Federally Funded Research

The Federal role has always encompassed the missions of Federal agencies and departments and, beyond those missions, has helped to sustain a healthy national infrastructure for S&T. The Federal role today is especially critical for research that is high risk, requires long-term investment in the expectation of future high payoffs to society or that is unlikely to be funded by the private sector; for unique, costly, cutting edge research facilities and instrumentation; and for academic research that, as a primary purpose, supports the education of the future science and engineering workforce.

The national science and technology enterprise has grown and become more pervasive in both the private sector and in government, even as the Federal share of support to the enterprise has declined. Now, more than ever, achieving Federal goals for sustaining U.S. leadership in S&T demands partnerships and cooperation with other sectors. Understanding where Federal funding can be best employed and the level of investment required to assure the health of U.S. science and technology are critical to prudent management of the Federal portfolio. Commitment to an intellectually well founded, long-term strategy for Federal research must be an integral aspect of a sound fiscal policy, regardless of year-to-year fluctuations in available funds. The Federal budget process for research must assure sustained and sufficient support for a diverse, flexible, opportunistic portfolio of investments, emphasizing the long-term health of the knowledge base and infrastructure for research—including human resources.

Box 2.

"The nation must reach a common ground and define a more realistic, pragmatic framework for allocating federal R&D resources. Only an inclusive national dialogue that brings together both the executive and legislative branches of government with the private sector and the U.S. university community will produce the needed consensus." --Council on Competitiveness, *Endless Frontier, Limited Resources*, 1996

Need for A Different Approach to Budget Coordination and Priority Setting

NSB discussions with spokespersons from Executive and Legislative branches and with experts on the budget, data and analytic methods, as well as reviews of the literature on budget coordination and priority setting identified the following needs.

Methodologies for:

- Determining the appropriate size of the enterprise;
- Determining the appropriate level of support to individual fields;
- Achieving balance in the portfolio;
- Setting priorities for the Nation's R&D enterprise;
- Achieving effective communication on scientific matters with the American people;
- Strengthening government-university partnerships.

Improved data, expert analyses, and scientific advice are needed to address these issues, including:

- A continuing mechanism for expert advice representing a broad cross-section of the science and engineering research and education community to support difficult decisions on research investments—especially in major infrastructure projects;
- Better quantitative data and methods of analysis adequate to measure the benefits of research;
- A mechanism to identify and track the relevant Federal funds for S&T through the budget process in the Administration and Congress.

The Current Federal System

The current Federal system for allocating funds for research is an incremental process that results in final allocation decisions based on input from a range of stakeholders, including the science and engineering communities. Ultimately, the Federal budget for research rests on aggregated political decisions in thirteen congressional appropriations subcommittees. There has been a host of critiques and suggestions for improving the process, many focused on the goals for research, but some suggesting changes to the process itself. The most frequent critique addresses a perceived lack of a clear methodology for priority setting and coordination. Several possible remedies have been suggested: structural changes to the process, alternative interpretations of the appropriate goals for Federal research, and new mechanisms for funding allocations and better management of the Federal research portfolio.

Since the late 1980s, and under both Republican and Democratic Administrations, there has been substantial attention devoted to developing better mechanisms for coordinating the Federal budget for research through the Office of Management and Budget (OMB) and the Office of Science and Technology Policy (OSTP) (Box 3).

“The Federal role today is especially critical for research that is high risk, requires long-term investment in the expectation of future high payoffs to society or that is unlikely to be funded by the private sector; for unique, costly, cutting edge research facilities and instrumentation; and for academic research that, as a primary purpose, supports the education of the future science and engineering workforce.”

Box 3. WHITE HOUSE S&T POLICY APPARATUS

Office of Science and Technology Policy (OSTP): The legislation that established OSTP declares that the United States shall adhere to a national policy for science and technology which includes the following principles: (1) the continuing development and implementation of a national strategy for determining and achieving the appropriate scope, level, direction, and extent of scientific and technological efforts based upon a continuous appraisal of the role of science and technology in achieving goals and formulating policies of the United States; (2) the enlistment of science and technology to foster a healthy economy in which the directions of growth and innovation are compatible with the prudent and frugal use of resources and with the preservation of a benign environment; and (3) the development and maintenance of a solid base for science and technology in the United States. It states the declaration of Congress that the Federal Government should maintain central policy-planning elements in the executive branch in mobilizing resources for essential science and technology programs, in securing appropriate funding for those programs, and to review systematically Federal science policy and programs and to recommend legislative amendments when needed. The functions of the Office include: (1) advise the President of scientific and technological considerations involved in areas of national concern; (2) evaluate the scale, quality, and effectiveness of the Federal effort in science and technology and advise on appropriate actions; (3) advise the President on scientific and technological considerations with regard to Federal budgets; and (4) assist the President in providing general leadership and coordination of the research and development programs of the Federal Government. (Excerpted from Public Law 94-292)

National Science And Technology Council (NSTC): The NSTC functions were to: 1) coordinate the science and technology policy-making process; 2) ensure science and technology policy decisions and programs are consistent with the President's stated goals; 3) help integrate the President's S&T policy agenda across the Federal Government; 4) ensure S&T are considered in development and implementation of Federal policies and programs; and 5) further international cooperation in science and technology (Executive Order 12881, November 23, 1993, Section 4).

Federal Coordinating Council for Science, Engineering and Technology (FCCSET): Established in 1976 under OSTP in the National Science and Technology Policy, Organization, and Priorities Act, FCCSET was "to consider problems and developments in fields of science, engineering, and technology and related activities affecting more than one Federal agency, and to recommend policies designed to provide more effective planning and administration of Federal scientific, engineering, and technological programs." (Title IV, Public Law 94-292).

The cabinet level National Science and Technology Council (NSTC) (Box 3) in the previous Administration and the earlier Federal Coordinating Council for Science, Engineering and Technology (FCCSET) (Box 3) provided mechanisms in OSTP for identifying major national initiatives that cut across agencies in designated priority areas (e.g., nanotechnology, global climate change, and information technology). Under the last Administration, the NSTC was established by Executive order as part of the OSTP science and technology policy apparatus. However, unlike FCCSET, OSTP and the Director of OSTP, which were established through legislation, the NSTC had no permanent status. Likewise, the President's Committee of Advisors on Science and Technology (PCAST), whose purpose was to provide "critical links to industry and academia," was established by Executive order.

Furthermore, in neither the Executive nor the Legislative branches is there a mechanism for evaluation that takes into account the breadth of Federal investments within the context of Federal goals for research. The Executive Branch, through OMB, OSTP and PCAST, made an effort to treat Federal funding of research as a portfolio, recently taking into account the issue of balance among fields of science in Federal support across all agencies and departments.

These steps have been in the right direction, but are only a preliminary effort. Congress (Box 4) also has directed attention to what might be done to improve its process but has not yet taken any action to implement formal Congressional mechanisms comparable to OSTP to coordinate functions across budget lines, agencies and departments, and committees.

Box 4. The Congressional Budget Process

At no time in the Congressional authorization or appropriations process is the R&D portfolio examined as a whole, across the Federal government. Impediments to coordination and informed priority setting exist in the form of budget "firewalls" between defense and civilian programs, and the reduction in advisory bodies for congressional R&D policy, planning and funding, including the Office of Assessment (OTA), and separate science units within Congressional Research Service and General Accounting Office. The House Science Policy Study, *Unlocking Our Future*, argues that "at a minimum Congress and the Executive Branch should improve their internal coordination processes to more effectively manage, execute, and integrate oversight...While the Office of Management and Budget can fill this role in the Executive Branch, no such mechanism exists in the Congress. In those cases where two or more Congressional committees have joint jurisdiction over or significant interest in large, complex technical programs, the affected committees should take steps to better coordinate their efforts. Wherever possible, the affected committees should consider holding joint hearings and perhaps even writing joint authorization bills."

To enhance the effectiveness of Federal investments in achieving long-term goals for research, a regular, credible process that relies in part on expert input from the science and engineering communities is essential for priority setting among

competing investment choices. The Federal portfolio for research is an accounting device that aggregates the research portfolios of the individual departments and agencies funding S&T. It has not been managed as a portfolio. As a precondition for priority setting across the Federal research budget, coordination must be achieved among its diverse components. While efforts at better coordination through OSTP mechanisms have been useful in managing cross agency initiatives, coordinating mechanisms are also necessary for evaluating the performance of Federal research investments as a portfolio and for identifying gaps, overlaps, areas for decreased emphasis, and the top priorities for additional investments. Coordination and priority setting therefore must be intertwined in the Federal research budget process.

The Need for More and Credible Data and Analyses

No mechanism exists to provide strong quantitative input to justify a particular level of investment in Federal research based on expected benefits to society, due in part to the lack of data and methods to measure research benefits. Data on Federal research funding, especially at the field level, are often unavailable on a timely basis to inform budget allocation decisions, use outdated research field definitions, fail to capture important characteristics of research activities, and suffer from inconsistent applications of definitions across reporting units.

Box 5.

"I doubt that anyone would sign on to a research project as poorly designed as our current national experiment in science and technology policy...our scientific enterprise remains adrift, without a connection to the broader society." –Representative George E. Brown, Jr., 1998.

In spite of the need for more and better data on the Federal research enterprise, collecting such data requires the cooperation of a large number of Federal agencies and departments, many of which see no benefit to themselves from this effort. There are few resources available to address the major undertaking that would be required to generate reliable data tailored to the needs of budget decisions and outcomes for research funding allocations. It would require a concerted effort to define and obtain agreement among the many Federal units that would be involved, and would require support from OMB and Congress to assure collection of high quality, timely data.

Identifying the Composition of the Federal Research Portfolio

OMB requires agencies to report research and development (R&D) activities that they are funding for the annual budget process. Even if reliably measured across funding units, since "D" at about 55% of the total is larger than "R", reporting the sum of the two as the measure of Federal research investment results in an indicator that fails to reflect accurately the Federal funding to discovery and innovation. Also, significant fluctuations in support for "research" tend to be obscured when combined with the larger "development" category funds.

There have been several attempts to provide a better measure for the federally funded activities that contribute to national innovation. The National Academies proposed a coordinated "Federal Science and Technology Budget" (NRC, 1995), a subset of Federal R&D that constitutes "federal support for a national science and technology base." The FS&T budget would provide Congress with a tool for tracking the

aggregated pool of Federal departmental and agency funds that support the science and technology base. OMB has employed over the last few budget cycles a similar mechanism for tracking the President's research priorities through the budget process. This mechanism comprised a collection of program budgets that are primarily research programs, but also includes non-research elements, such as the education and human resources component of the budget for NSF. OMB found this mechanism useful in highlighting Federal research investments and effective in supporting the President's priorities for research through the budget cycle.

The Board, for the purposes of this study, has focused on "S&T", in accord with the argument put forward in the NRC report and efforts by OMB to identify basic and applied research activities for tracking through the budget process. At the same time the Board recognizes the lack of consensus on federally funded activities that should comprise Federal "S&T". Criteria for inclusion of activities in a Federal budget for research for the purpose of monitoring and evaluating Federal activities as a portfolio will require further discussion and analysis. The important subset of research funding devoted to the long-term, high-risk basic research is especially vulnerable to becoming invisible in the larger budget for S&T. It is critical that this component--which provides the long-term investment to produce as yet unforeseen major breakthroughs in knowledge--receive sustained public support.

Capturing the Character of Activities Supported

Within research, the character of research fields and activities has changed over time, resulting in definitions that no longer capture important distinctions in federally funded research activities. Special areas of weakness include multidisciplinary and cross disciplinary workgroups and teams, emerging areas, differences in interpretation across agencies' reporting units, and the evolving content of traditional research fields themselves. In addition, educational contributions of research--particularly in academic institutions for graduate education--are not captured in most agencies' databases.

Reliability and Timeliness

Differences in interpretation have resulted in wide discrepancies in research funding reported by performing and funding units--or even within the Federal government across agencies and programs—even though they ostensibly describe the same activities. In addition, timeliness, in most cases essential to budget allocation decisions, is not possible with Federal databases based on surveys. Much of the data measuring the Federal research portfolio with respect to programs funded, support for fields of science and engineering, and performing institutions are several years old at best. Timeliness will become increasingly more problematic as rapid changes in science and technology increase the need for current data to monitor Federal investments.

Assessing World Leadership of U.S. Science and Engineering

National capabilities in science and technology and the government role in enhancing these assets are a growing emphasis for governments around the world. As science and technology capabilities have become more broadly distributed, there is a need for

the U.S. to monitor the U.S. enterprise against an international backdrop to detect declines in national capabilities in science and technology relative to other nations or to identify new opportunities for research investment that merit public support. The National Academies have urged regular international benchmarking at the field level to assess the health of individual fields of research in the U.S. in their 1993 report, *Science, Technology and the Federal Government/National Goals for a New Era* and their 1995 report, *Allocating Federal Funds for Science and Technology*. The use of international comparisons of the productivity of research fields and international expert participation in assessments of research programs are common in other countries.

The Board has noted the need for monitoring the relative health of U.S. science and technology as part of a continuing evaluation of the Federal portfolio, drawing on existing data and expert analyses, and continually improving data and methods for international comparisons that inform priority setting.

Understanding the Role of Federal Research in Producing Economic and Other Benefits

Box 6.

"In the long run—in good budget years as in bad—it is essential that policymakers...recognize the fragility of (the U.S. S&T) enterprise and the critical federal role in sustaining it. It is up to the members of the science and engineering community to carry this message to them" – A.H. Teich, AAAS, 1999

A large number of studies have attempted to elucidate, and in many cases measure quantitatively, the relationship between research and innovation and the benefits of research for society. Organizations like the Council on Competitiveness, the Science and Technology Policy Institute, RAND; OSTP, and NSF have explored issues and methods for analyzing the role of a range of factors in innovation--including Federally funded research--and resulting economic and social benefits. Academic programs for addressing these questions are inadequately funded. This

is an area where additional research investment could improve both qualitative and quantitative data to inform budget allocation decisions, communicate the benefits of research to the public, and contribute to the effectiveness of Federal research investments.

III. MAJOR FINDINGS AND ISSUES

The Board's preliminary findings are based on an intensive two-year study including review of the literature on Federal budget coordination and priority setting for science and engineering research, invited presentations from and discussions with representatives of OMB, OSTP, the Federal R&D agencies, Congressional staff, high level science officials from eight foreign governments, experts on data and methodologies, and industry and academic spokespersons. Discussions focused on research priority setting as it is practiced within government organizations and suggestions on how the process might be improved. After considering this information, the Board finds that:

- Federal priority setting for research occurs at three levels: 1) in setting Federal goals for research, 2) in the budget allocation processes for research within the White House and the Congress that in the aggregate produce the Federal research portfolio and 3) in Federal agencies and departments in achieving their missions and in accord with the President's priorities for research. The appropriate level for the Board to focus on enhancements is the second level.
- The allocation of funds to research is primarily a political process that should be informed by the best scientific advice and data available.
- A strengthened process for research allocation decisions is needed. Such allocations are based now primarily on faith in future payoffs, which are difficult to defend against alternative claims on the budget that promise concrete, more easily measured results and are supported by large and vocal constituencies.
- The pluralistic framework for Federal research is a positive aspect of the system, and increases possibilities for funding high risk, high payoff research. An improved process for budget coordination and priority setting should build on strengths of the current system and focus on those weaknesses that can be addressed by improved scientific input.
- There is a need for regular evaluation of Federal investments as a portfolio for success in achieving Federal goals for research, to identify areas of weakness in national infrastructure for S&T, and to identify a limited set of the top priorities for new research investments.
- Additional resources are needed to provide both Congress and the Executive branches with data, analyses and expert advice to inform their decisions on budget allocations for research.

Appropriate Scientific Advice

The scientific community can contribute to the Federal budget process as it now does within departments, agencies and programs, by providing:

- Reliable data and expert opinion on the most compelling major opportunities and needs for science and engineering, in the form of a small set of top research priorities for substantial additional Federal investment;
- Scientific advice including a mechanism to help in priority setting across fields of science and including multidisciplinary research and emerging areas;
- Estimating costs and benefits of various proposals, as well as overall funding levels, as input to decisions.

At the Federal level, advice on priorities for major research facilities is an area for particular attention. Facilities costs must be estimated and include long-term commitments for operation and maintenance. In addition, consideration must be given to tradeoffs to enable funding for priority facilities.

Alignment of the research budget advice and data with the Congressional budget process is essential if it is to be useful in Congressional allocation decisions.

Improved Data and Analysis

Allocation decisions should be informed by available data and should employ a range of methods of analysis and data sources. Over the long term there is a need for improvements in data, methods, and analyses that track Federal funds and measure the costs and benefits of research. Needs include:

- Broadly acceptable definitions of “research” especially at the field level--though admittedly difficult to establish--to enable unambiguous, self-consistent tracking of Federal funds and benefits across departments, agencies and sectors;
- Improved data for international comparisons, including both relative and absolute measures;
- Improved databases and other tools for tracking research funds and measuring outputs;
- Improved theoretical understanding of the relationship between publicly supported research and innovation;
- Improved measures of economic returns to research investments, as well as non-economic returns in improved quality of life; and
- Improved understanding of the relationship between research investments and the workforce.

Toward an Enhanced Process

The analytical and expert support available to inform research budget decisions need to be strengthened in both the Congress and the White House. A primary resource that would provide immediate benefits to decision makers is a broad-based, continuous capability for expert advice to both OMB and Congress during the budget allocation process. A longer-term need is the regular, systematic evaluation of the effectiveness of Federal investments in achieving Federal goals for research through OSTP. Complementing both are improved data and analysis on research opportunities and needs that trace Federal research investments through the budget process and beyond.

Strengthening the Federal mechanisms to inform research budget allocation decisions in the White House would add an important dimension to current mechanisms for scientific advice, which feature agency and department-based external and internal scientific input as part of their budget deliberations. It would require additional staff resources in OSTP and perhaps in Congress. Furthermore, investments in data systems and in academic research on the relationship between publicly funded research and economic and social benefits would enable improvements in methods for measuring and estimating returns on public investments. The payoff would be a more effective system for allocating Federal research funds to contribute to national goals, and improved tools for measuring and communicating the benefits of Federal investments to policy makers and the general public.

IV. CONCLUSIONS AND RECOMMENDATIONS

U.S. global leadership in science and technology has contributed enormously to national wealth and the quality of life. Today the capabilities for cutting edge science and engineering are becoming distributed more broadly throughout the industrialized and developing world. To maintain U.S. leadership, Federal funding is critical for long-term, high risk, and academic research, as well as unique research facilities and instrumentation. The White House and Congress must employ the best available information and scientific advice in research budget allocation decisions to assure the continued strength of the U.S. science and technology.

A deliberate, scientifically grounded process is essential for identifying opportunities and needs for research. Needs include human resources, instrumentation and facilities, alignment of the portfolio of Federal investments with national priorities for research, effective distribution of funding among research modes and performing organizations, closure of gaps in research resulting from changes in department and agency programs, and addressing patterns of underinvestment in vital areas of fundamental research.

Federally funded science and technology support the missions of every Federal department and agency, and have enormous long-term impacts on the economy and the quality of life of American citizens. The explosion of knowledge and new technologies over the last decade has expanded opportunities for breakthroughs in a broad range of science and engineering fields. The growth in opportunities for discovery and innovation requires the Federal government to make wise, well-informed choices for funding allocations that provide the greatest benefits over the long term to American society. Making those choices requires forward looking advice by experts, evaluation of the current Federal portfolio, and an information system to track investments and outcomes and to evaluate long-term opportunities as well as current needs for support in a global as well as domestic context.

The Board finds that the mechanisms that have evolved based on the OSTP Act of 1976 and the cooperation between OSTP and OMB represent valuable progress toward a more coherent and sophisticated system to inform major decisions on Federal research investments. Strengthening the OMB/OSTP/PCAST mechanisms would provide a strong information base for congressional decisions. Additional, complementary resources to provide timely expert and data input to the congressional budget processes are also needed.

RECOMMENDATION 1: KEYSTONE RECOMMENDATION

The Federal government, including the White House, Federal departments and agencies, and the Congress should cooperate in developing and supporting a more productive process for allocating and coordinating Federal research funding. The process must place a priority on investments in areas that advance important national goals, identify areas ready to benefit from greater investment, address long-term needs and opportunities for Federal missions and

responsibilities, and ensure world class fundamental science and engineering capabilities across the frontiers of knowledge.

Research Community Input on Needs and Opportunities

Steps can be taken in the short term to improve the information base for Federal research investments. Effective funding decisions must be based on the best possible information on scientific opportunities and needs, and on national goals for science and engineering. A primary input to any process of priority setting for research is expert scientific advice on current and long-term opportunities and needs for research. Presently there is no widely accepted and broadly applied way for the Federal government to obtain systematic input from the science and engineering communities for making priority decisions about support for research and research infrastructure.

There is insufficient opportunity and capability within the framework of existing mechanisms for Federal research priority setting to undertake timely and broad-based assessments of the needs for Federal investments. A more effective system for managing the Federal research portfolio requires adequate funding, staffing and organizational continuity.

RECOMMENDATION 2:

A process should be implemented that identifies priority needs and opportunities for research--encompassing all major areas of science and engineering--to inform Federal budget decisions. The process should include an evaluation of the current Federal portfolio for research in light of national goals, and draw on systematic, independent expert advice, studies of the costs and benefits of research investments, and analyses of available data. The priorities identified would inform OMB in developing its guidance to Federal departments and agencies for the President's budget submission, and the Congress in the budget development and appropriations processes.

1. Executive Branch Advisory Mechanism

The Executive Branch should implement a more robust advisory mechanism, expanding on and enhancing current White House mechanisms for S&T budget coordination and priority setting. Resources available to OSTP, OMB and PCAST should be bolstered to permit more timely, broad-based data analysis to produce a comprehensive evaluation of the Federal portfolio for science and technology research on a five-year cycle,¹ updated annually as input to the Federal budget process. Enhanced resources should include an adequate professional staff. A model to consider is the Council of Economic Advisors, which is supported by a rotating professional staff. It is particularly essential

¹ The designation of a five-year cycle for evaluation of the Federal portfolio reflects both the size of the effort, which would require more than an annual process, and the rapid changes in science, which demand a frequent reevaluation of needs and opportunities for investments.

that the advisory mechanism include participants who are experienced in making choices among excellent opportunities or needs for research. (For example, vice provosts for research in universities, active researchers with breadth of vision, and managers of major industrial research programs would be appropriate in this role.)

RECOMMENDATION 2a:

An Executive Branch process for periodic evaluation of outcomes of the Federal portfolio for research in light of Federal goals for S&T should be implemented on a five-year cycle. A report to the President and Congress should be prepared including a list of the highest long-term priorities for Federal research investments. These priorities should include new national initiatives, unique and paradigm shifting instrumentation and facilities, unintended and unanticipated shifts in support among areas of research resulting in gaps in support to important research domains, and emerging fields. The report should also include potential trade-offs to provide greater funding for priority activities. The report should be updated on an annual basis as part of the budget process, and should employ the best available data and analyses as well as expert input.

2. Congressional Advisory Mechanism

Congress is inadequately supported in making allocation decisions for research. Analytical resources for science and technology policy tailored to Congressional needs have been eliminated or reduced in recent years, while the need for such resources is growing. There is no mechanism for considering allocation decisions for research within the framework of the broad Federal research portfolio. The current system splits areas of research among committees, each considering a limited portion of the portfolio. Though improvements in the White House process would benefit Congressional allocation decisions, a Congressional mechanism to provide expert input to research allocation decisions is badly needed.

RECOMMENDATION 2b:

Congress should develop an appropriate mechanism to provide it with independent expert S&T review, evaluation, and advice.

The advisory process should make use of the best available data and analyses in deriving its recommendations on Federal priorities and funding levels.

Long-Term Investments in Improved Data and Analyses

In addition to an enhanced process for expert advice and assessment, there is a long-term need to improve tools -- databases and analytic methods -- for effective management of the Federal research portfolio.

1. *Definitions, Data and Data Systems*

High quality data and data systems to monitor Federal investments in research would enhance the decision process. Such systems must be based on definitions of research activities that are consistently applied across departments and agencies and measured to capture the changing character of research and research needs. Flexibility in defining categories of research for tracking purposes is especially important for monitoring emerging areas and addressing the range of modes for research -- from the individual investigator to the major center or facility. Timely collection of data and ease of access are critical to be useful to the allocation decision process.

Improving data and data systems is a long-term objective, but one that is necessary and increasingly urgent for managing the large, diverse Federal research portfolio to serve the Nation. It will require long-term commitment to improve data systems, with input from potential users and contributors, and appropriate support.

RECOMMENDATION 3:

A strategy for addressing data needs should be developed. Such a strategy supported by OMB and Congress would assure commitment by departments, agencies and programs to timely, accessible data that are reliable across reporting units and relevant to the needs for monitoring and evaluating Federal investments in research. Current data and data systems tracking federally-funded research should be evaluated for utility to the research budget allocation process and employed as appropriate.

2. *International Comparisons*

Both relative and absolute international statistical data and assessments should be included as a major component of the information base to support Executive branch and Congressional research budget allocation decisions. International benchmarking of U.S. research performance and capabilities on a regular basis responds to the growing globalization of science and technology and the need for the U.S. to maintain a world class science and engineering infrastructure. Maintaining world class capabilities enables the Nation to take advantage of opportunities for rapid advancements in knowledge in targeted areas of research and to capitalize on breakthroughs wherever they occur worldwide. Although international data and methods of analysis are limited, they should be employed with sensitivity to those limitations and with a long-

term commitment to developing better methods and data for monitoring U.S. performance and strength in science and technology.

International comparisons should include a range of measures of national research resources and performance to produce objective assessments of the relative strength of the U.S. in research areas important to national goals. For example, comparisons could include total national S&T investment as a share of Gross Domestic Product (GDP) or as a share of the high technology sector of the economy. Relative performance of individual fields important to national economic or defense priorities can be assessed using bibliometric methods and patent citations. Comparisons should be sensitive to the appropriate basis for comparing different economies, since the composition of the economy may be as important as its size as measured by GDP. For example, it might not be appropriate to compare S&T/GDP ratios for two economies that have very different manufacturing shares of total GDP. Of central importance is the comparison of human resources for research in priority areas in the U.S. and in other countries, including international migration of science and engineering personnel as well as participation by U.S. students in science and engineering studies in comparison with other nations.

Statistical trends are critical for evaluating the adequacy and direction of national research investments. Comparisons might include the following types of relative and absolute statistics:

- Total national S&T; Defense S&T; Civilian S&T; Basic (fundamental) research: National (US) and Federal;
- Civilian S&T by functional categories of: health, energy, environment and natural resources, space research and technology, general science, transportation, agriculture;
- Basic science investment categories, such as: engineering, natural sciences, social science, and mathematical sciences; and
- Human resources engaged in or available for research by field, degree attainment, gender and nationality.

RECOMMENDATION 4:

Input to Federal allocation decisions should include comparisons of U.S. research resources and performance with those of other countries. National resources and performance should be benchmarked to evaluate the health and vigor of U.S. science and engineering for a range of macroeconomic indicators, using both absolute and relative measures, the latter to control in part for the difference in size and composition of economies. Over the long term, data sources should be expanded and quality improved.

3. *Federal Research Benefits to the Economy and Society*

In addition to monitoring Federal expenditures for research, measuring the benefits to the public of funded research is essential for prudent management. Although there is an extensive literature on methods for measuring returns on research investments, usually in the private sector, these methods have not been widely applied in the Federal context for a number of reasons. With regard to economic methods, the difficulties include lack of sufficient data, questions of data quality, selection bias in case studies of specific industries and problems of time lags between research discoveries and their impacts on the economy. In the case of publicly supported research, many benefits cannot be expressed in terms of economic returns. Indicators and methods that have been used for measuring benefits of research include the following:

- Asset-oriented measures, which tally such system “assets” as research facilities and human resources for S&T resulting from Federal investments—for example, immigrant and native-born scientists and engineers, and graduate students supported on Federal research grants;
- Outputs measures, which track intellectual contributions and often employ bibliometric analysis—such as patent citations, publication counts, article citations, presentations at conferences--or honors received by researchers and research projects, e.g. Nobel prizes;
- Outcomes or results measures, including: (1) case studies and retrospective analyses, which are usually qualitative, tracing the inputs and the processes that produced an important innovation and (2) quantitative economic techniques such as production function analysis and surveys estimating economic impacts of public research within specific industries and enabling a better understanding of the channels and mechanisms whereby public research contributes to innovation.

Implementation of this recommendation should be coordinated with Recommendation 3 on definitions and data systems.

RECOMMENDATION 5:

The Federal government should invest in the research necessary to build the intellectual infrastructure in the higher education sector to analyze substantive effects on the economy and quality of life of Federal support for science and technology. The research should include improvements to methods for measuring returns on public investments in research.

Federal support for research has been highly successful in contributing to the quality of life that we enjoy in the U.S. today. Continued national commitment to publicly supported research offers the promise of even greater benefits in the future. The expanding frontiers of knowledge demand careful evaluation to identify the highest priorities for investment of Federal research funds. It is therefore essential that the processes by which allocation decisions are made rest on the best possible

information base that high technology and well prepared minds can produce. The systematic participation of the scientific community in this process, bringing its vision and understanding of the needs and opportunities for research, is critical to its success. The Board's recommendations describe a strategy for improving the quality, content, and accessibility of science and engineering input to decisions on the allocation of Federal research funds. We are aware that implementing these recommendations will be difficult and require long-term commitment. In the interest of science and the Nation, we urge that the Federal government and its partners in the research community embrace this difficult task.