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Analysis of Ten Selected Science and Technology Policy Studies

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Summary

Since the end of the Cold War in the early 1990s, a number of reports have been prepared on a broad range of science and technology (S&T) policy issues. Reports dealing with national research and development (R&D) goals, priorities, and budgets, and university-government-industry relationships are among those of current interest to Congress. Ten S&T reports dealing with those subjects, completed since 1991, were selected and analyzed for this CRS report.

During the Cold War period from 1945 to about 1990, the U.S. S&T system grew rapidly as a result of a number of forces. The report of Vannevar Bush in 1945, during a period of major S&T system restructuring immediately following World War II, set the tone for much of the nation's subsequent R&D growth and S&T policy development. The Bush report is the subject of much current interest for the lessons it may have for future U.S. S&T policy development. In addition, policy adjustments were made from time to time by Congress and the Administration. Three different types of adjustment are identified and discussed: major S&T system restructuring, reaction to crisis, and "fine tuning" of the S&T system.

Major cross-cutting themes emerged from the analysis of the ten documents summarized in this report. All noted that significant national and international changes are affecting the nation's S&T system. They discussed three kinds of responses: new mechanisms for determining the nation's S&T goals, priorities, and budgets; new models of research, development, and innovation, and refinement of the roles of government, industry, and academia in each; and changes in university research and the university/government relationship.

The reports identified a number of major changes that have occurred in the world at large and in science and technology over the past several years, such as the end of the Cold War and increasing international economic and scientific competition. Such changes provided and continue to provide both opportunities and problems for the U.S. S&T system. The reports contained many recommendations on how the U.S. S&T system, and especially the U.S. government R&D establishment, can respond. Many recommendations centered on the need for new mechanisms for determining national S&T goals and priorities and federal R&D budgets. Questions were raised in the reports about the current understanding (the "Bush model") of the relationship of basic to applied research, and the relationship of those types of research to innovation Several recommendations in the reports called for a new understanding of these terms and new models of their relationships. Changes since the end of the Cold War also have affected academia significantly, including its funding by the federal government, the balance between teaching and research in universities, and the increasing need in industry and government for persons with doctorates.

Acknowledgments

William C. Boesman is the coordinator and principal author of the background and analysis sections and one of the report summaries. Other CRS specialists who prepared report summaries and contributed to the Appendix are Michael E. Davey, Eric Fischer, Genevieve Knezo, Christine Matthews, John Moteff, and Richard E. Rowberg of the Science Policy Research Division.

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Introduction

The Cold War period saw the creation and maturation of a large research and development (R&D) establishment in the United States, funded primarily by industry and the federal government. Since the end of the Cold War, that system, particularly the federally-funded portion, has been subjected to changing stresses. As a result, several reports from various sources have been prepared analyzing a broad range of science and technology (S&T) policy issues. Among them are reports dealing with national R&D goals, priorities, and budgets, and university-government-industry relationships. As it reviews current U.S. science policy, the Congress has been addressing these and related issues, and has expressed interest in the content of those studies. In addition, there appears to be special interest in the report of Vannevar Bush,[1] a fundamental and guiding document in U.S. S&T policy since the post-World War II era, for lessons to be learned in considering options for change in U.S. science policy, whether major or incremental.

To assist in that effort, CRS has reviewed a cross section of those studies. Ten reports completed since 1991 were selected and each was summarized in two to five pages. The documents were selected in consultation with experts in S&T policy in the Congressional Research Service and in other organizations involved with the subject. They were selected from among a large number of reports of merit based upon one or more of the following criteria: they are recognized as influential reports, express a range of views, were done by leaders in the field, focus on one or more of the subjects to be covered, or represent views of current policymakers. The ten reports are not exhaustive in range and, although they cover a number of policy viewpoints, may not reflect all perspectives. The section containing the report summaries is followed by a section that presents a brief analysis of major cross-cutting themes identified in the ten reports.

Preceding the summary and analysis sections of this report is a section that provides a brief background of some major S&T policy efforts since the Bush report, including major congressional hearings and study efforts. An appendix contains a listing of some policy study efforts currently underway in the S&T policy community.

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[1] Vannevar Bush, *Science -- The Endless Frontier* (Reprint) (Washington: National Science Foundation, May 1980), 192 p.

Background

The history of the American science and technology system[2] is coextensive with the history of the nation. From the patent clause in the U.S. Constitution to the most recent scientific discoveries, technological applications, and federal R&D programs, science and technology have been integral to the nation's development. As the nation developed, so did its S&T system. The system achieved its present structure mainly during and immediately following World War II. Many issues are associated with this complex and evolving system, including

- the strength of the nation's defense-related R&D,
- the adequacy of the S&T system in support of a strong domestic economy, and international scientific cooperation and economic competition,
- the balance between defense and civilian R&D,
- the balance between the federal and nonfederal (industry, academia, other) sectors,
- the federal role in basic and applied research, and development,
- the adequacy of, and constraints on, federal R&D budgets,
- present and future numbers of scientific and engineering personnel,
- congressional R&D policy making and legislation,
- executive branch R&D policy making and management (Executive Office of the President and R&D departments and agencies),
- specific programs of the federal R&D mission agencies,
- critical national S&T problems and opportunities, and
- the long-term overall strength of the U.S. S&T system.

During different periods since World War II, these and other S&T issues have been dealt with by U.S. policymakers in different ways or with different emphases influenced by circumstances. For purposes of analysis, this report notes three broad types of system change: major S&T system restructuring, reaction to crisis, and "fine tuning" of the S&T system. While these situations are not mutually exclusive (fine tuning, for example, occurring even in periods of crisis), it is useful to discuss the American S&T system since World War II in these terms to better evaluate the current period of U.S. S&T policy and what may follow.

Major System Restructuring

The period immediately following World War II was one of major restructuring of the S&T system from the defense-dominated war effort to what evolved into the Cold War. In 1944, President Roosevelt asked Vannevar Bush, the director of the Office of Scientific Research and Development, which was responsible for the U.S. wartime R&D effort, to prepare a report on how to take advantage of the nation's great S&T capabilities, consistent with national security secrecy restrictions, in the

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[2] U.S. Library of Congress. Congressional Research Service. *Federal Research and Development Funding: A Concise History*, by Richard E. Rowberg, Report 95-1209 SPR, Dec. 15, 1995, 11 p.

postwar years. In 1945, the Bush report, *Science — The Endless Frontier,* [3] was submitted to President Truman.

The Bush report reasoned that, because scientific progress is essential for the nation, science is a proper concern of government, the latter statement confirmed by the great contribution of science and technology to the war effort. This conclusion echoed, in part, the finding of a report of the National Resources Committee, the prewar focus of federal science planning, that federal support of research was an appropriate responsibility of the federal government and might help the United States out of the Great Depression.[4] Bush convened four committees, which submitted their reports to him: the Medical Advisory Committee, the Committee on Science and the Public Welfare, the Committee on the Discovery and Development of Scientific Talent, and the Committee on Publication of Scientific Information.

Major conclusions of the Bush report, based upon the work of the committees, were that the government "should extend financial support to basic medical research in the medical schools and in universities"; fund "civilian-controlled" military research in support of that conducted by the Armed Services; support the general welfare by funding basic research in academia and, in regard to applied research, by improving the procedures for hiring and retaining federal scientific personnel and by providing tax and patent incentives to industry; provide "a reasonable number" of undergraduate scholarships and graduate fellowships to develop the nation's scientific talent, especially those currently in the Armed Services; and declassify secret scientific information as rapidly as possible.[5]

The Bush report also called for the establishment of a National Research Foundation, which was to be the central scientific agency within the federal government. Although there was a consensus on this idea by 1945, the two major proponents, Bush and Senator Kilgore, differed on some important matters, such as whether the new organization should mainly support basic research (proposed by Bush) or R&D broadly (proposed by Kilgore) in furtherance of societal goals. Another major issue was political control of the organization. President Truman vetoed the first bill because it did not provide for presidential appointment of the director. It took until 1950 before those issues were resolved and the National Science Foundation (NSF) was established. In the interim, however, several other federal R&D agencies also were established (e.g., the Atomic Energy Commission and the Office of Naval Research) and R&D responsibilities and capabilities of other agencies (e.g., the National Institutes of Health (NIH)) were increased. Consequently, NSF was not the government's central scientific agency as was originally envisioned.[6] Nevertheless, the Bush report has played an important role in

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[3] Bush, *Science — The Endless Frontier*, op. cit.

[4] National Resources Committee, *Research--A National Resource*, 3 vols. Washington, D.C.: GPO, 1935-41.

[5] Bush, *Science--The Endless Frontier*, op. cit., 5-8.

[6] U.S. Library of Congress. Congressional Research Service. *Federal Support of Basic Research and the Establishment of the National Science Foundation and Other Research*

(continued...)

U.S. science policy up to the present in laying down guiding principles for federally-funded R&D and for establishing strong support for university-performed basic research.

Reaction to Crisis

The evolution of the U.S. S&T system also received significant direction as S&T policymakers responded to several periods of national crisis since World War II. One "crisis" was the Soviet Union's 1957 launching of *Sputnik*, the Earth's first artificial satellite. That caused a widespread fear of the impending domination of military space efforts by the Soviets as well as concern about Soviet technological leadership. The United States responded in several ways, including the establishment of the predecessor committee of the House Science Committee, the enactment of the National Defense Education Act[7], the creation of the National Aeronautics and Space Administration (NASA), the creation within the Department of Defense of the Defense Advanced Research Projects Agency (DARPA), and greatly expanded budgets for the nation's military and civilian space efforts.

Another national crisis to which the S&T system responded was the Arab oil embargo of 1973. Congress responded with the enactment of the Energy Reorganization Act of 1974,[8] which, among other things, established the Energy Research and Development Administration; the enactment of the Department of Energy Organization Act[9] in 1977, which established the Department of Energy (DOE).

A comparable development, although it may be termed a major adjustment to an existing situation (the Soviet military threat) rather than a response to a new crisis, was the large increase in defense-related R&D funding during the 1980s. Begun during the last year of the Carter Administration, federal defense-related R&D funding reached a peak of about 70% of total federal R&D funding in 1986 after reaching a postwar low of about 50% in 1979. By 1996, preliminary estimates of defense-related R&D funding had decreased again to about 51%, nearly the 1979 level, although the final figure for 1996 probably will be higher.[10]

In addition, the entire period from about 1965 to about 1980 has been characterized by various analysts as a period of science and technology policy

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[6](...continued)
Agencies, by William C. Boesman, Report 88-456 SPR, June 28, 1988, 22 p.

[7] Public Law 85-864, 72 Stat. 1580, (2 September 1958).

[8] Public Law 93-438, 88 Stat. 1233, (11 October 1974).

[9] Public Law 95-91, 91 Stat. 565, (4 August 1997).

[10] National Science Foundation, National Patterns of R&D Resources: 1996 (NSF 96-333) Arlington, VA.: National Science Foundation, 1996: 99-100. Estimates for 1995 and 1996 are preliminary. CRS estimates that the final figures may be closer to 53% or 54 %.

"disarray"[11] or "crisis."[12] Strains within the system arose from shifting S&T priorities, toward, for example, civilian R&D. Strains also resulted from the slowing of the expansion that had begun in World War II and that had continued with the rapidly increasing space budgets of the early 1960s. Other strains that impacted on the S&T system were a number of societal and political pressures, including those caused by the Vietnam War, the struggle for civil rights, and the conservation and environmental movements. Perhaps most important to the S&T community was the new belief by a significant segment of the citizenry that the nation's problems could not be solved by science and technology. That was symbolized by the inability of the most powerful nation in the world to subdue a technologically inferior enemy in Vietnam. As one analyst saw matters,

> [s]ociety's support for science had been based on the assumption that progress in the various scientific disciplines would ultimately lay the foundation for a better life for all Americans. . . . But as Americans lost confidence in this premise, as their optimism about the future became tinged with pessimism, the foundations of society's support for science — and scientists' faith in themselves — eroded.[13]

One significant attempt to address societal needs through the application of science and technology during this period, was the Research Applied to National Needs (RANN) program of the National Science Foundation. In part because of doubt concerning the role the federal government should play in civilian applied research, the program, established in 1971, was abolished in 1978.

Because of various strains on the nation's S&T system during this period, there was a movement for the establishment of a national science and technology policy and for strengthening the President's Science Advisory Committee (PSAC, established by President Eisenhower) and the Office of Science and Technology (OST, established by President Kennedy). In 1970, for example, the House Subcommittee on Science, Research, and Development (the "Daddario Subcommittee") of the Committee on Science and Astronautics held a series of hearings on the history of national science policy since World War II.[14] President Nixon did not support the legislative enactment of an S&T policy and, in 1973, abolished both PSAC and OST. Under the Administration of President Ford, the National Science and Technology Policy, Organization, and Priorities Act of 1976[15] was enacted. It provided a national policy for science and technology and established, within the Executive Office of the

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[11] Bruce L.R. Smith, *American Science Policy Since World War II*, Washington: The Brookings Institution, 1990: 73-107.

[12] U.S. Congress. House. Committee on Science and Technology, *Science Policy Study Background Report No. 1: A History of Science Policy in the United States, 1940-1985*, Task Force on Science Policy, 99th Cong., 2d sess., 1986, Committee Print, 57-70.

[13] Smith, *American Science Policy Since World War II*, op. cit., 77.

[14] U.S. Congress. House. Hearing before the Committee on Science and Astronautics, *Toward a Science Policy for the United States*, 91st Cong., 2d sess., 1970.

[15] Public Law 94-282, 90 Stat. 459, 42 USC 6601 et seq., (May 11, 1976).

President (EXOP), the Office of Science and Technology Policy (OSTP) and the Federal Coordinating Council for Science, Engineering, and Technology (FCCSET).

In 1972, the congressional Office of Technology Assessment (OTA) was established[16] in an attempt to address imbalances in S&T analytical capabilities between the legislative and executive branches by providing Congress with additional independent S&T analytical capabilities, especially in assessing the impacts of technology on society.

With the ebbing of some political and societal crises (Vietnam and Watergate), the establishment of a new national science and technology policy and a new policy structure within the EXOP, and increasing R&D budgets by the end of the Carter Administration, the period of science and technology policy "disarray" appeared to be over, although major disagreements, for example, about the increasing share of resources devoted by the Reagan Administration to defense-related R&D, would continue.

Fine Tuning

The government continually "fine tunes" the federal R&D system and, to a much lesser extent, the nonfederal S&T system, through its S&T policies and annual R&D budgets. This fine tuning results in incremental change aimed at improving the nation's S&T system or adapting it to changes. In addition, from time to time, government and private sector entities conduct major S&T policy study efforts. Two such major science policy study efforts occurred during the early 1960s, just before the period of "policy disarray" discussed above: by the "Elliott Committee" and the "Daddario Subcommittee" of the House of Representatives.

The Elliott Committee was the House Select Committee on Government Research which, during its existence in 1963 and 1964, reviewed the R&D programs of nine federal departments and 12 agencies, submitted ten major studies, and made over 40 recommendations. The Daddario Subcommittee, during its existence from 1963 through 1970, conducted a number of hearings and produced a number of reports on "Government and Science." As set forth in its 1963 statement of purpose, the reason for the study was that the federal government was then providing "more than two-thirds of the total research and development money being spent in the United States."[17] In fact, the federal share of R&D funding peaked at 66.5% in 1964 and decreased to below 60% by 1969. It has further decreased to about 34% at present, the lowest share reported by NSF in its 44-year-old R&D data series.[18]

The most recent comprehensive congressional science policy study effort was that of the Science Policy Task Force of the House Committee on Science and

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[16] Public Law 92-484, 86 Stat. 797, (Oct. 13, 1972). OTA was abolished in 1995.

[17] U.S. Congress. House. Committee on Science and Astronautics, *Government and Science No. 1: A Statement of Purpose,* Subcommittee on Science, Research, and Development, 88th Cong., 1st sess., 1963, Committee Print, 11.

[18] *National Patterns of R&D Resources: 1996*, op. cit., 77.

Technology during the mid-1980s. That effort might be viewed by some as fitting better into the preceding categories of "major S&T system restructuring" or "reaction to crisis" rather than "fine tuning." Indeed, one of the two "strong factors [that] made such a review highly desirable" was the "urgent need to reverse the growing trend of huge deficits in the federal budget,"[19] which was widely perceived as a major crisis. However, the chairman, in his discussion of possibly establishing a department of science and technology, stated:

> [O]ur recognized problems revolve around the pace of technological development and commercialization, and not primarily the performance of American science. I do not believe that the best way to approach these problems is through the reorganization of federal science activities.[20]

The study was a comprehensive review of American science and technology (40 years back to the Bush report) with a focus on the long-range (40-year) future. A major emphasis of the study was basic and applied research supported by the government in academia, industry, and its own laboratories, with emphasis on the health of American colleges and universities in the future.

During 1985 and 1986, the Task Force held 66 days of hearings on 25 science policy areas. Fourteen background reports on separate subjects were prepared. The chairman's report has served as a summary of the efforts of the Task Force. It discussed 19 topics (interdisciplinary research, national laboratories, regulatory climate, international cooperation, big and little science, Department of Defense research, energy, health research, biotechnology, space, education, computers, materials, museums, social sciences, peer review, ethics, a Department of Science and Technology, and technology), most of which were covered in the hearings and background reports, but some of which (energy, space, biotechnology, and materials) expressed the chairman's views. The report contained 62 recommendations.

In the next (100th) Congress, the same committee[21] established a Technology Policy Task Force. It held ten hearings and produced seven reports, four of which were hearings summaries, including ones on technical enterprises for computers, communications, and manufacturing in the 20th Century; commercial development of medical biotechnology; and the effects of technological change on the labor force.

The final report of the Technology Policy Task Force[22] discussed technology and the economy, specifically the role of government in technology, the effects of government policies on technology, and the human resources and industrial sectors involved. The report made six recommendations:

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[19] U.S. Congress. House. Committee on Science and Technology, *American Science and Science Policy Issues: Chairman's Report*, 99th Cong., 2d sess., 1986, Committee Print, 2.

[20] Ibid., 119.

[21] Renamed the Committee on Science, Space, and Technology.

[22] U.S. Congress. House. Committee on Science, Space, and Technology, *Technology Policy and Its Effect on the National Economy*, Technology Policy Task Force, 100th Cong., 2d sess., Committee Print, 1989, 240 p.

- The Committee should further investigate the kind of organization within the government that would enhance American technology and draft legislative language to establish such an organization.

- The Committee should investigate the charter of each national laboratory and NASA centers to determine the capabilities which qualify them to support specific industrial areas.

- The four remaining recommendations were that the Committee should explore opportunities for authorizing civilian R&D for the U.S. Corps of Engineers to support the construction industry, consider legislation for pilot programs in urban areas to improve technical achievement in school children, consider legislation for restoring the U.S. consumer electronics manufacturing industry, and consider legislation to designate an existing higher education establishment to host a National Institute of Manufacturing Engineering and Management.

The final Technology Policy Task Force report noted that "government should not and can not [sic] prescribe programs for industry or even recommend areas of technology where industry should concentrate its resources."[23] Noting further, however, that the government already affects industry through a broad range of trade, education, regulatory, tax, patent, and other policies, it recommended a national policy on technology that encompassed its six recommendations.

In the 102d Congress, the same committee established the Task Force on the Health of Science. Unlike the other two task forces discussed above, this task force effort was not intended to be comprehensive, but to "expand the current science policy dialogue, which has been too narrowly focused on funding levels, and not sufficiently concerned with the structure of the research system."[24] The Task Force made use of informal, off-the-record briefings from active members of the research policy community and commissioned several performance assessments, by outside groups, of a number of different research efforts conducted by the nation's research communities and federal R&D agencies.

In reviewing national science policy since the Bush report, the report concluded that the "real question is whether available resources are being allocated in a manner that can best achieve national goals. Yet this question has never been addressed in a comprehensive manner."[25] The basis of the Task Force's recommendations was that, in this era in which the U.S. S&T system is perceived to be under "stress," federal R&D priorities should not be driven by fiscal concerns and circumscribed by the boundaries of scientific disciplines. Rather, the report stated that, for each national goal, including those that still need to be adequately defined, the policy questions

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[23] Ibid., XIII.

[24] U.S. Congress. House. Committee on Science, Space, and Technology, Report of the Task Force on Health of Research: Chairman's Report, 102d Cong., 2d sess., 1992, Committee Print, 19 p.

[25] Ibid., 7.

should be "what research is most necessary [and] what mechanisms for administering, preforming, and evaluating research create the optimal pathways from research to goal attainment?"[26]

Because of the complex structure of the executive branch and the many congressional committees with jurisdiction over some aspect of R&D, the Task Force sought "to outline broad strategies by which the [Committee] can strengthen its oversight of the federally funded research portfolio, while crafting policy directed at improving the linkages between federally funded research programs and national goals." It recommended two principal strategies:

> Strengthen mechanisms for setting government-wide research-policy goals, and for oversight of the federal research portfolio, by exploiting Committee jurisdiction over the Office of Science and Technology Policy (OSTP);
>
> Integrate various performance assessment mechanisms into the research process using legislative mandates, in order to help measure the effectiveness of federally funded research programs.[27]

The report looked beyond the continuous need to fine tune the nation's S&T system. It suggested that:

> [T]he Committee may wish to consider a fundamental reformulation of science policy principles, with the view toward exploiting research as a tool designed to achieve national goals, rather than as a black box into which federal funds are deposited and from which social benefit is somehow derived.[28]

The issues of establishing national S&T goals, S&T priority setting, and fine tuning or restructuring the national S&T system have continued during the 1990s. Selected reports discussing these subjects are summarized below.

The Current Situation

The Cold War is over. To some, this marks a turning point in U.S. science and technology policy as important as the end of World War II. However, militarily the world is still a dangerous place. The Gulf War, peacekeeping missions, terrorist attacks, and various regional conflicts since 1990, all show the importance of continued development of military technology.

Economically, the nation is facing increased competition from large (Japan and Germany) and small (Singapore, South Korea, and Taiwan) high-technology

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[26] Ibid., 10.

[27] Ibid., 4.

[28] Ibid., 10-11.

countries. Hong Kong, another "Asian tiger," recently has been incorporated into China, which itself is developing rapidly with a labor force of about 600 million.[29]

In the United States, federal R&D budgets generally have decreased in constant dollars since 1988, while nongovernmental R&D funding has increased. Currently, federal R&D accounts for about 35% of national R&D funding, down from the peak of about 66.5% in 1964[30] and the lowest level since World War II. The federal government is in a period of adjustment of its relationships with industry and academia.

In addition, many S&T problems and opportunities will continue to be addressed by major federal civilian space, energy, environmental, biomedical and public health, basic research, and science, engineering, and mathematics education programs, as well as by the private industrial sector and academia.

Federal science policymakers may wish to address whether the time is ripe for a major evaluation of the nation's S&T system or whether continued fine tuning is all that is required now. Some questions that could be asked are:

- The Bush report contributed to major changes in the nation's S&T system following World War II. Do current national and international circumstances warrant a mandate for another major restructuring of the nation's S&T system? The Bush report, for example, called for major structural changes in the federal R&D bureaucracy. Is that needed today? What is the role of the private sector and market forces?

- Alternatively, is it time for another major study effort aimed at fine tuning the existing S&T system? It has been, for example, about 11 years since the conclusion of the major science policy study of the House Science Committee and about four years since the concluding report of Carnegie Commission on Science, Technology, and Government. Many recommendations have been implemented, but additional changes to the nation's S&T system might be necessary.

- If no major study effort is now warranted, critical discussion is sustained by reports on specific aspects of the nation's S&T system published continually as problems and opportunities arise and are addressed. Recently, for example, studies of the impact of decreasing federal funding on academia have been published. What are the important areas of current concern to S&T policymakers that warrant study to determine what specific changes might be necessary?

To assist Congress in addressing these types of questions, ten selected reports, representing a cross section of recent study efforts, are summarized in the next

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[29] Central Intelligence Agency, *The World Factbook 1995*: 88.

[30] *National Patterns of R&D Resources: 1996*, op. cit., 77-78. U.S. national R&D funding in 1996 was about $184.3 billion.

section. The subsequent section presents an analysis of the cross-cutting issues identified in the ten reports.

Summaries of Selected Science and Technology Policy Reports

Federally Funded Research: Decisions for a Decade

U.S. Congress. Office of Technology Assessment. *Federally Funded Research: Decision for a Decade*. (OTA-SET-490) Washington: U.S. Govt. Print. Off., May 1991, 314 p.

Overview. In December 1989, the House Committee on Science Space, and Technology requested that the Office of Technology Assessment (OTA) provide it with "information on the nature and distribution of research funding and decisionmaking" (p. 4). It was specifically interested "in understanding the state of the federally funded research system — its goals, research choices, policies, and outcomes — and the challenges that it would face in the 1990s." This request was as a follow-up to: (1) the 1988 report, *Federal Science and Technology Budget Priorities: New Perspectives and Procedures*, prepared by the National Academy of Sciences (NAS), National Academy of Engineering (NAE), and Institute of Medicine (IOM) as the first of several studies by the Academy complex on the need for explicit priority setting in R&D, and (2) hearings held by the House Science and Technology Committee on the Academy report.[31]

The 1988 NAS study had been requested by the Congress in the Conference Report on the Concurrent Resolution on the Budget for FY 1989, June 6, 1988, which called for the Academy complex to "provide advice on developing an appropriate institutional framework and information base for conducting cross-program development and review of the nation's research and development."[32] The NAS-NAE-IOM report identified four categories of S&T priorities warranting support, including agency missions, the S&T base, national objectives, and major S&T initiatives. The report recommended that the federal budget enunciate presidential S&T priorities for cross-cutting S&T initiatives, that a "task force" be created cutting across committee lines in the House and Senate to examine the S&T budget as a whole, that appropriations committees review cross-cutting S&T priorities, and that Congress initiate biennial congressional budgeting for S&T.

The Academy and OTA reports were prepared during an inflationary cycle, and at a time when R&D budgets were expected to be constrained because nondefense

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[31] U.S. Congress. House. Committee on Science, Space, and Technology. Subcommittee on Science, Research, and Technology, *The Adequacy Direction, and Priorities for the American Science and Technology Effort*, l01st Cong., (February 29-March 1, 1989).

[32] Report of the Committee on the Budget on S. Con. Res. 113, Concurrent Resolution on the Budget FY 1989 (Sen. Rept. 100-311) as cited in *Federal Science and Technology Budget Priorities: New Perspectives and Procedures*, p. 17.

discretionary real spending was anticipated to increase only about 2% annually. Large increases were projected for "big sciences projects," including the space station, the Superconducting Super Collider (SSC), the human genome project, and doubling of NSF's budget over a five year period, which could foreclose increases for research support in other areas. Many of the recommendations in the OTA report concur with and elaborate upon those in the NAS report.

The OTA report contains eight chapters, totaling 260 pages, and eight appendices. It is an extensively documented description and analysis of major issues in funding research and development. It contains considerable data, references to contemporaneous studies on science policy and R&D decisionmaking, and case studies and descriptions of agency R&D decisionmaking processes.. It incorporates the results of "expert" workshops and contractor reports. Individual chapters focus on "The Value of Science and the Changing Research Economy," "The Federal Research System: The Executive and Legislative Branches," "The Federal Research System: The Research Agencies," "Priority Setting in Science," "Understanding Research Expenditures," "Human Resources for the Research Workforce," and "Data on the Federal Research System."

Issues. The report described the overall increase in federal funding for research "from roughly $8 billion in 1960 (in 1990 dollars) to over $21 billion in 1990." This was due initially to "escalation of the Cold War and the Presidential commitment to land men on the Moon," followed by a slight decrease and leveling off from the late 1960s to about 1975, then an increase in funding "due in large part to the expansion in health and life sciences research" (p. 5). During the 30 year period, the number of academic researchers grew steadily, so that " there will always be more opportunities than can be funded, more researchers competing than can be sustained, and more institutions seeking to expand than the prime sponsor — the federal government — can fund" (p. 7). "The objective, then, is to ensure that the best researchers continue to be funded, that a full portfolio of research is maintained, and that there is a sufficient research work force of the highest caliber to do the job" (p. 7).

Findings. Four major issues would challenge the federal research system in the 1990s, according to OTA, including: (1) setting priorities in the support of research; (2) understanding research expenditures; (3) adapting education and human resources to meet the changing needs of the research work force; and (4) refining data collection, analysis, and interpretation to improve federal R&D decision making.

Recommendations. The report offered "issues and options" for each issue-- which largely were recommendations -- even though OTA was statutorily prohibited from making recommendations.

On the first issue, *setting priorities in the support of research,* the report found that federal priority setting falls short in three ways: "criteria used in selecting various areas of research and megaprojects are not made explicit and vary widely," especially in high-level Office of Management and Budget (OMB) and congressional decision-making; there is no mechanism to evaluate the total research portfolio in terms of progress toward many national objectives; and the issues of developing human resources and regional and institutional capacity need to be considered along with the "principal criteria for selection, scientific merit and mission relevance" (p. 11). OTA suggested numerous executive and legislative actions to cope with these problems.

Congress cannot look only to the scientific community for guidance on setting priorities, warned OTA, due to the absence of scientific tradition for "ranking research topics [and investment choices] across fields and subfields." Thus, like the 1988 Academy report, OTA stated that "Congress should hold biennial hearings...on the state of the research system, including cross-field priorities in science and engineering and the criteria used for decision making within the cognizant research agencies" (p. 21). This would "require the research agencies, OSTP, and OMB to present co-ordinated budget plans . . . that cut across scientific disciplines and research areas. Coordination among relevant committees of Congress would make this most productive" (p. 43). As will be discussed below, other types of congressional action were recommended to deal with the other problems. OTA emphasized that "[T]o effect changes in the research system, congressional action must be comprehensive and sustained. Posture hearings with the Science Advisor and agency directors will not suffice" (p. 44).

When establishing priorities, executive branch agencies could provide the Congress with more "transparent" and iterative planning information, that makes tradeoffs and reflects the application of criteria of merit, program relevance, and other goals that reveal the relationships among new and continuing projects, the support of new investigators, and the changing costs and duration of research in relation to capacity building. "Congress could also initiate specific changes in the executive agencies that would increase their ability to respond to changing priorities," (p. 21) including measures to encourage flexibility, risk-taking, strategic planning, coordination, and new methods of funding.

The second issue, *understanding research expenditures*, addressed the observation that "federal expenditures for individual components of research projects have increased faster than inflation. Understanding and coping with these increases is imperative in research decision making." (p. 43). According to the report, there are inconsistences in defining what is meant by the costs of doing research, both in terms of inputs, which vary because of salaries, indirect costs (which are the largest component increase in research project budgets, (p. 24), stage of the research process, equipment costs, and likelihood of competitors, and in terms of outputs, such as performance, or cost per unit output. OTA discussed various options to lower costs, including "fixed-price grants" and congressional pursuit of programs to develop "permanent grant-reducing measures to slow or limit increases in research expenditures on individual research grants," greater cost-accountability by performers, and more accuracy in developing estimates of costs for megaprojects (p. 26-27). "[C]ongressional actions [presumably in the form of hearings] could explore cost-accountability efforts at the research agencies and throughout the research system" (p. 43). The government should also try to balance the demand for more research output by its performers, especially in academia where researchers are driven by the need to "publish" in order to advance professionally, against the actual need for more research.

The third issue that OTA examined, *adapting education and human resources to meet changing needs*, focused on the controversial topic of supply and demand for scientific personnel. OTA concluded that then-current predictions of shortages of scientific personnel were overstated and should not be used to formulate public policy. Demand for personnel, even outside of government, may depend on levels of federal funding. In order to maintain required capacity, government should continue programs to expand the number and diversity of students in the "education pipeline" and to "prepar[e] . . . graduate students for career paths in or outside of research." (p. 28). OTA endorsed legislative action in support of minorities and women, "set-aside" programs, and other activities to enlarge the diversity of the workforce.

The report addressed the issue of selective augmentation of academic research capacity: "by encouraging 'have-not' institutions to concentrate excellence in select research programs (departments and centers) and build from there" (p. 33). Priority choices have to be made when expanding academic research capacity because "across-the-board enhancement of all research programs may lead to each program being unable to garner enough support to improve research capability" (p. 33). The report endorsed programs to build capacity in lagging States or regions, like the Experimental Program to Stimulate Competitive Research (EPSCOR) program, and noted the tension between research and teaching in academia and the need for universities to play a greater role in diversifying the careers of recent Ph.Ds. It concluded that it was important to share research equipment, space, and people in teams or interdisciplinary centers, what it called "a larger, more 'industrial' model, with shared "infrastructure."

In discussing the fourth issue, *refining data collection and analysis to improve research decision making*, OTA said that "four categories of data . . . could be useful in decision making: (1) research monies — how they are allocated and spent; (2) personnel — characteristics of the research workforce; (3) the research process — how researchers spend their time and what their needs are (e.g. equipment and communication) for research performance; and (4) outcomes — the results of research." Gaps and uncertainties characterize these kinds of data, with NIH and NSF being the agencies that collect the best data. Other agencies rarely collect the kinds of internal statistics needed to inform research decision making and identify problems. OTA recommended that all agencies that support research should provide comparable data, using common definitions to identify the size of the research workforce; expenditures, including salaries, equipment, and indirect costs; the size of research groups and research "production units" and their relative dependence upon the government and other funding sources; and "[numbers of] proposal submissions and awards" (p. 40). "Congress could instruct every research agency to develop a baseline of information, direct NSF to expand its focus and coordinating function for data collection and analysis, and direct OSTP (in conjunction with OMB) to devise a plan to increase the reporting and use of agency data in the budget process, especially cross cutting information in priority research areas" (p. 41). Congressional hearings ought to be held to "examine the state of data on the research system and improvements [needed] to inform congressional decisionmaking" (p. 43).

The OTA report also addressed the issue of measuring the evaluation of research outcomes and said that while there is merit in quantitative measures, such as degrees awarded and citation rates, it also was important to include peer and expert judgments, using such criteria as "the originality of research results, the project's efficiency and costs, impacts on education and the research infrastructure, and overall scientific merit" (p. 39). This discussion evoked debates, still in progress, about how to implement the Government Performance and Results Act in federal research and development activities.

Science, Technology, and Government for a Changing World

Carnegie Commission on Science, Technology, and Government. *Science, Technology, and Government for a Changing World.* New York: Carnegie Commission on Science, Technology, and Government, April 1993, 94 p.

Overview. This is the 1993 summary report of the five-year effort of the Carnegie Commission on Science, Technology, and Government, established by the philanthropic Carnegie Corporation of New York in April 1988. The Commission was composed of over 200 S&T experts organized into several task forces. It included a number of distinguished scientists, industrialists, lawyers, politicians and former government officials, including Presidents Ford and Carter. The Commission produced 19 reports and about 12 other background and related studies. It also sponsored six books and studies published by others. From 1993 through 1996, the Commission staff continued follow-up work and task force chairmen discussed many of their reports' recommendations with government officials. In 1996 the Commission met for the last time and approved a final report on science and technology and the President for "the next [Clinton] administration." The formal reports of the Commission are listed in an appendix of the summary report. Reports were published in 15 major science and technology policy areas. In 14 of these areas, one or more formal Commission reports were published. In the area of recruiting and retaining federal scientists and engineers, no formal report was prepared by the Commission, although reports were published by other organizations.

Issues. The 15 S&T policy areas addressed by the Commission dealt with the President, the Congress, the federal judiciary, the States, U.S. international affairs, global development, international S&T decision making by governments and intergovernmental organizations, U.S. national security, the nation's economic performance and technology base, K-12 science and mathematics education, environmental research and development, the role of S&T in regulatory decision making, nongovernmental S&T organizations, federal scientists and engineers, and long-term national goals for science and technology.

Findings/Conclusions. The impetus for the Carnegie Commission on Science, Technology, and Government came from David A. Hamburg, President of the Carnegie Corporation of New York who was concerned about the "profound difficulty of meeting the challenge of accelerating scientific and technological developments." With a mandate to study this broad subject, the Commission, in its summary report, "calls for a transformation in the way science and technology policymaking is organized in all branches of government in order to meet the challenges of the human future — encouraging long-term economic growth; sustaining the environment; and creating and maintaining peaceful relations among nations in the post-Cold War world.[33] To contribute to such a "transformation" to meet the challenges of the future, the Commission in its several reports made over 300 recommendations.

Recommendations. This summary report includes 15 short (two- to three-page) chapters, each authored by a Commission leader in one of the 15 S&T policy areas. Each chapter summarizes major findings and conclusions of the Commission's previous report or reports in these areas.

According to spokesmen for the Commission, many changes have been made in federal science and technology policy as a result of these recommendations. Examples of implemented recommendations include the elevation of the President's science advisor to Cabinet status and the reestablishment of the President's Science Advisory Committee (PSAC) as the President's Council of Advisors on Science and Technology (PCAST) in the Bush Administration; the early appointment of the President's science advisor in the Clinton Administration and the formulation of its technology policy, "which is very much in tune with the recommendations of the Commission;" and increased collaboration between the National Science Foundation and the Department of Education on federal efforts for K-12 mathematics and science education, which was agreed to formally by these two agencies in 1992. The Commission's view on the need to link the economy, energy, and the environment in the development of national policy now has "become conventional wisdom" and contributed to the decision to eliminate the Council on Environmental Quality and create an Office of Environmental Policy.[34] Examples of other major recommendations mentioned in the summary report (and, in a few cases, from the individual reports), many of which recommend specific changes in executive branch agencies, follow.

The White House. In addition to implemented recommendations, such as those noted above, the strength of the Office of Science and Technology Policy should be maintained. High-level mechanisms must be strengthened to enhance cross-cutting analyses in such policy areas as environmnt, energy, and the economy. The Federal Coordinating Council for Science, Engineering, and Technology should be convened regularly at cabinet level with the participation of the Director of the Office of Management and Budget.

Congress. Three reports on obtaining expert advice for the congressional decision-making process, improving the congressional support agencies (Congressional Research Service, General Accounting Office, and Congressional Budget Office), and improving the internal organization and procedures of Congress for dealing with S&T issues include recommendations for reorganizing congressional committees, shifting to a multi-year budget cycle, reducing earmarking through the use of merit review, and establishing a Congressional Science and Technology Study Conference as a legislative service organization and a nonprofit Science and

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[33] Carnegie Commission on Science, Technology, and Government, *Carnegie Commission Concluding Report Calls for Changes in the Way Government Organizes Science and Technology Policymaking* [Information bulletin], 1 April 1993: 1.

[34] Ibid., 3-4.

Technology Study Institute to facilitate communication between Congress and the scientific and engineering communities.

Judicial Decision Making. Because of the increasing number of complex S&T-related cases, a nongovernmental Science and Justice Council should be established to monitor and initiate changes that may have an impact on the abilities of courts to manage and adjudicate such cases. In addition to the judicial reference manual already prepared by a Commission task force to help judges better manage S&T issues, improved S&T reference materials and resource capabilities should be developed for the entire judicial system.

States. With the end of the Cold War, there is a need to strike a new balance between the federal government and the States in applying science and technology to national needs. The States should become full partners with the federal government in S&T policy making, such as by being represented on federal S&T advisory and decision-making organizations, including those defining missions for federal laboratories. Each State should establish science advisors to their governors and S&T advisory boards for their legislatures and aim toward the establishment of a national organization to assist the States in S&T matters.

International Affairs.. Congressional and presidential decisions are required to better integrate international policy and actions with science and technology, and to clarify international S&T responsibilities across federal mission agencies, and particularly in the Department of State. The position of Science and Technology Counselor to the Secretary of State should be established and the number of science and technology officers in U.S. embassies should be increased.[35]

Global Development. Science and technology are powerful tools for international development, but their effective application requires presidential leadership. In addition, a National Action Roundtable for International Development should be established to mobilize the government, the private sector, and not-for-profit institutions for specific challenges and the U.S. Agency for International Development should increase its access to American science and technology and improve its operations in many ways.

International Science Advice. Because international S&T decision making is becoming increasingly important, especially in big science and global projects, the advisory capabilities of international nongovernmental scientific organizations should be strengthened. In regard to the especially important area of international environmental research and cooperation, a Consultative Group for REsearch on ENvironment (CGREEN) should be created and existing organizations, like the International Council of Scientific Unions, should be strengthened.

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[35] The Department of State recently eliminated its highest-ranking S&T position, the deputy assistant secretary for science, technology, and health and reorganized the Bureau of Oceans and International Environmental and Scientific Affairs (OES), a step seen by some as continuing the decline in the role of science in the department. See, Ken Jacobson, "State Drops Top S&T Post, Puts Chips On Environment," *New Technology Week*, v. 11, 28 July ,1997: 1,6-7.

National Security. In the post-Cold War era of declining defense budgets, steps should be taken to integrate the nation's defense and civilian technology bases to form a single industrial base, reform the defense acquisition system from a regulation-based to a market-based procurement system, strengthen the Defense Science Board, establish a high-level national security science and technology advisor in the White House, and broaden the charter of the Defense Advanced Research Projects Agency (DARPA) from its exclusive emphasis on defense.

Economic Performance and the Technology Base. To shape and implement federal policy related to economic performance and the national technology base, including movement toward a single dual-use (commercial and military) technology base, technology policy in the Executive Office of the President should be enhanced, the Department of Commerce should play a more active role by forging strong partnerships with business, labor, and universities (including an expanded role for the Advanced Technology Program of the National Institute of Standards and Technology), and DARPA should be transformed into the National Advanced Research Projects Agency (NARPA)[36] as a step toward creating a broader national technology base.

Mathematics and Science Education. K-12 education is mainly a State and local responsibility, but the system has proven to be inadequate in regard to science and mathematics education. Presidential leadership and bipartisan commitment is necessary if the nation's educational system is to be improved significantly. Although a number of the Commission's recommendations have been adopted (see above), continued federal leadership in K-12 mathematics and science education policy will be required for the next two or more decades,

Environmental Research and Development. Although some Commission recommendations have already been adopted (see above), the government's environmental R&D system, impressive in many ways, but diffuse and uncoordinated, should be further reorganized and integrated by, for example, establishing a U.S. Environmental Monitoring Agency by combining the National Oceanic and Atmospheric Administration and the U.S. Geological Survey, by a presidential Environmental Research and Monitoring Initiative, and by consolidating 12 laboratories of the Environmental Protection Agency into four.

Regulation. The Executive Office of the President, in cooperation with the other two branches of government, should take the lead in providing broad policy guidance to regulatory agencies and in setting and implementing coherent regulatory priorities. The Food and Drug Administration, the Occupational Safety and Health Administration, the Environmental Protection Agency, the Consumer Product Safety Commission, and other regulatory agencies should compile risk inventories and conduct risk analyses.

Nongovernmental S&T Organizations. This task force, surprised that 2000 to 4000 S&T-related nongovernmental organizations (NGOs) exist in this country, and

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[36] "Defense" was dropped from DARPA's name in 1994, but was restored later to emphasize its continued close relation to defense-related R&D.

acknowledging them as a *de facto* fourth S&T policy player along with government, industry, and the research universities, stressed that the governing bodies of these scientific and technical NGOs should monitor the independence, objectivity, and accountability of their organizations in their interactions with government. However, providing policy advice is not appropriate for every NGO.

Government's Technical Leadership. Although the Commission did not produce a formal report on this subject, four books, including three published by the National Academy of Sciences, recommended improvements in recruitment and the reduction of barriers to assure that the most qualified scientists and engineers fill the approximately 80 top technical presidential appointments and that agencies in the Executive Office of the President and the Congress develop improved personnel policies (including salaries comparable to the private sector) for the approximately 200,000 scientists and engineers employed by the federal government, the single largest employer of scientists and engineers in the nation.

Long-Term S&T Goals. To encourage long-term thinking about goals linking science and technology to society, both within and outside of government, mechanisms for institutionalizing long-term S&T goal-setting should be instituted within the policymaking and budget-making processes of Congress and the executive branch. A nongovernmental National Forum on Science and Technology Goals should be established as a forum for the exchange of ideas about future S&T policies and goals among all major sectors of society.

Science, Technology, and the Federal Government: National Goals for a New Era

National Academy of Sciences. Committee on Science, Engineering, and Public Policy. *Science, Technology, and the Federal Government: National Goals for a New Era*. Washington: DC: National Academy Press, 1993, 54 p.

Overview. *Science, Technology, and the Federal Government* claimed that major changes over the last decade and more have changed the framework for science and technology in the United States. It examined how the U.S. S&T enterprise can best respond to the new framework, and in particular, what should be the role of the federal government. The report was written by the Committee on Science, Engineering, and Public Policy (COSEPUP), a joint standing committee of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The committee consisted of experts in a range of fields in S&T. Most members were from academe. The report is often called "the Griffiths report," after the committee chair, Phillip A. Griffiths. It divided the S&T enterprise into three parts: research, technology development, and education and training. The report addresses the first two parts.

Issues. The changes that the Griffiths report identified include the increasing prominence in society of the products of science and technology, the end of the Cold War, the information revolution, major medical advances, and increasing intensity in international economic and scientific competition. Corporate research and development also has been changing. In particular, it has decreased in the United

States, especially with respect to other countries. There also have been changes in how S&T activities are performed. The number of large-scale, major projects has increased, and the nation is experiencing a possible saturation of the market for new Ph.D.s in the sciences. Furthermore, some people are questioning the historical assumption that S&T makes needed contributions to national objectives. For example, some question how continuing increases in government investment in medical research can be justified with health care becoming more expensive despite (or perhaps because of) that research. Others point out that environmental problems persist despite substantial investment in research.

Findings. The report found that U.S. economic and national security depends on making better use of U.S. global scientific leadership and engineering capabilities. U.S. strength in S&T has contributed fundamentally to the rise of the country to its current position of global leadership and can continue to contribute to it. Industry, health care, the military, and environmental protection all depend on S&T and will continue to do so. In addition, the advances in knowledge from scientific research have changed and enriched society in profound ways beyond the material.

Science and technology are used in different ways to meet different societal needs. Many industries are born out of science (e.g., biotechnology, the semiconductor industry), but industries depend less on science as they mature (e.g., aircraft, automobiles). High-tech industries do not necessarily depend on current fundamental research (e.g., semiconductors). Defense has become more dependent on civilian technologies, which is a shift from previous decades.

It is impossible to predict reliably which areas of science will contribute new technologies. Therefore, resources currently used for research to advance knowledge, if redirected to more immediate or practical research goals, would reduce the potential for new discoveries that would advance society and the economy and would not necessarily solve the immediate problems being addressed.

To continue and enhance the U.S. global leadership position, the federal government needs improved ways to judge the health of the S&T enterprise and its various components. It must also respond to changing workforce needs as the economy develops further, the information revolution continues, S&T and the industries they support become increasingly internationalized, and U.S. education continues to evolve.

Recommendations. The report made several recommendations aimed at ensuring continuing and enhanced U.S. global leadership in S&T. The two core ideas were the call for an explicit national goal of maintaining global leadership in S&T, and the idea of identifying a position of leadership through the deliberations of independent panels of experts.

Investment in S&T. To guide U.S. investment in the wide range of possible S&T activities, the report recommended that, for some major areas of science, the United States should be the global leader, and that it should strive to be among the world leaders for all major areas of science. "Areas" means broad disciplines and their major subdisciplines, such as biology and neuroscience. Being "among the leaders" means that U.S. capabilities and infrastructure in the area should not be exceeded by other countries.

By ensuring such excellence, the U.S. can bring knowledge to bear within and across disciplines on needs relating to national objectives, can take advantage of advances made in other countries, and can attract the best talent in S&T.

Among the areas in which the United States should be the leader are fields for which national objectives can be met only if the nation is leader, or that capture the imagination of the public, or that affect other areas of science disproportionately. The choices should involve comparative assessment of different fields. They should involve a different mechanism than decisions about the best direction within a field, which should be made by the scientists in that area.

The report asserted that these goals can be met within current total federal funding levels. The reason given was that the United States is already a leader in many areas, and small re-allocations could have major effects on others.

Measuring national performance. The Griffiths report recommended that the United States perform field-by-field peer assessments, via panels of independent scientists, of U.S. research compared with that of other countries. Those assessments would help identify strengths and barriers within and among fields and help resolve debates over megaprojects. They would be used to guide priorities for investment, but steps should also be taken to make the federal budgetary process for science more "coherent," using mechanisms already in place, such as OSTP committees.

One question about this recommendation is how one would designate an area to be examined. The delineation of areas might be difficult and contentious. Once such designations occur, there is also the risk that they could also lead to an unintended rigidification of fields and create the very barriers to interdisciplinary work that the report criticizes. To test the idea, COSEPUP is engaging in a series of "bench marking" exercises, in which committees of experts will assess chosen areas of research in the United States in comparison to other countries. Three areas currently being examined are mathematics, materials science and engineering, and immunology.[37]

Other recommendations. Establishment of leadership will also entail use of merit review to ensure quality research; adequate, stable funding for qualified investigators, involving a minimum administrative burden; mechanisms to encourage interdisciplinary work and emerging fields; and investment in education to ensure the continuous development of the research workforce.

In cooperation with the private sector, the federal government should work "to ensure that the United States maintains a position of technological leadership" (p. 33) in areas of major, broad industrial and economic impact. That goal cannot be achieved primarily through federal policies, but the government should "create an

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[37] Deborah Stine, COSEPUP staff officer, telephone conversation with author, 12 August 1997.

environment in which technology flourishes" (p. 37). The federal government should support the development of promising new technologies in cases where industry will not "because the necessary research and development may be too costly, lengthy, or risky for an individual company" (p. 38). Examples where the federal government has performed such a function in the past include aeronautics, semiconductors, computers and satellite communications. They were supported for national security reasons. But other projects, such as synfuels and breeder reactors, failed.

Allocating Federal Funds for Science and Technology

National Academy of Sciences, National Research Council. *Allocating Federal Funds for Science and Technology*. Washington: National Academy Press, 1995, 96 p.

Overview. The National Research Council produced *Allocating Federal Funds for Science and Technology* in response to a congressional request to examine "the criteria that should be used in judging the appropriate balance of funds to research and development activities, the appropriate balance among different types of institutions that conduct such research, and the means of assuring continued objectivity in the allocation process."[38] The report was written by a committee of 18 experts from academe and industry, including former government officials, and chaired by Frank Press. It is often referred to as the "Press report."

Issues. Perhaps the major issue influencing the committee's deliberations was the increasing current and projected constraints on federal funding for R&D resulting from sustained efforts to balance the federal budget. Additional considerations included the re-emergence of proposals to create a Department of Science and the changing environment for R&D created by the end of the Cold War and increasing global economic competition.

Findings. Many people consider the federal government's investment in research and development to be essential for meeting many national needs. A major strength is the breadth of fields supported and the diversity of agency involvement, making resources available to respond quickly to unforseen problems such as AIDS, in addition to meeting mission-specific needs. Universities have been an especially important locus of investment. Stable, thoughtful investment can solve many problems cost-effectively, but it is often not possible to predict what specific investment will lead to major advances, especially in technology.

The current system of funding and managing R&D evolved during times of funding growth and mission expansion. Because it has progressed by building new structures, rather than changing old ones, it is not as well-suited to times of constricting budgets. While individual scientists and engineers can readily adapt to changing priorities, adaptation is much more difficult for large research institutions.

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[38] The report language cited (p. 87) also states that the Senate Appropriations Committee was "concerned whether [the federal research and development budget] is designed to meet new national security concerns, military, economic, and health, that confront our Nation in a post-cold war world. The Committee is concerned, for example, that medical research is not at its optimal level of priority and support relative to its importance to national security."

In 1994, the federal government invested $70 billion in R&D. Of that amount, $35 to $40 billion went to federal science and technology (FS&T), with the rest being spent on projects that were "neither long-term investments in new knowledge nor investments in creating substantially new applications" (p. 57). Those short-term activities included "initial production, maintenance, and upgrading of large-scale weapons and space systems at the Department of Defense, Department of Energy, and the National Aeronautics and Space Administration" (p. 52).

The pooling of these two very different kinds of expenditure masks federal investment in science and technology at a time when a focus on such investments is "especially important" (p. 54). The Department of Defense has begun to distinguish between the two. It considers basic research and development "science and technology," and its other expenditures "systems development."[39] Other agencies do not make similar distinctions.

Most agencies traditionally distinguish between basic and applied research. However, that distinction is often difficult to make in practice and is usually not as important in decision making as other factors. The relationship between the two kinds of research is complex, and "most federally funded research is at once both applied and basic" (p. 77). In addition, federal investment in science and technology has a complex relationship with industrial involvement, with government support "central to creating national economic advantage" (p. 81).

Recommendations. The report has 13 recommendations altogether. Several focus on the budget process, and several parallel recommendations made in the Griffiths report.[40]

The central recommendation was that the federal government should create a specific "FS&T budget" and use it in making funding decisions. The budget would include the $35 to $40 billion identified above as science and technology investment. The report envisioned that the FS&T budget would be presented by the President and considered by Congress as part of the allocation process. The premise for this recommendation was that a coordinated approach to budgeting is necessary in a time of budget reduction. Different fields of S&T depend on each other, and a comprehensive FS&T budget would permit consideration of how cuts in one area could affect others. It would thereby lessen the risk that cuts in one programmatic area could inadvertently damage the health of another, higher-priority field.

The proposed creation of a separate FS&T budget was the most central and original recommendation in the report. "The strength of the FS&T budget concept

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[39] DOD currently uses seven numbered R&D categories: research (6.1), exploratory development (6.2), advanced technology development (6.3), demonstration and validation (6.4), engineering and manufacturing development (6.5), management support (6.6), and operational system development (6.7). The first three are classified as science and technology programs.

[40] National Academy of Sciences, *Science, Technology, and the Federal Government: National Goals for a New Era*, (Washington, DC: National Academy Press, 1993); also discussed in this CRS report.

is that it corresponds to the set of research and technology development activities typically conducted in the science and engineering departments of U.S. research universities, many of the federal laboratories and FFRDCs [Federally Funded Research and Development Centers], and some private firms" (p. 54). The approach would "focus on the investment aspects of federal science and technology..." "...[i]n a period of severe constraints on the federal budget and reduced allocations for R&D..." (p. 54).

The concept has been criticized on the grounds that it would not have the desired effect.[41] On the one hand, it might be considered largely irrelevant to the political process through which the budget is allocated. The comparative priorities within the FS&T budget might carry little weight compared to other considerations within agencies and congressional committees. On the other hand, it might set up a "zero-sum game" situation for S&T funding, whereby the amount identified in the budget acts essentially as a cap. Alternatively, it might actually reduce the connection of S&T investment to national goals by focusing on comparisons within the S&T enterprise rather than with respect to other means of achieving the goal.

The National Academy of Sciences has used the proposed FS&T budget approach to produce analyses of the Administration's budget request to Congress for FY1997 and FY1998. However, those analyses are essentially post-hoc cross-cuts and do not indicate how decision-making would be affected by adopting the approach. The Academy is currently considering using an FS&T budget analysis to determine the impact of changes in the federal budget on science and technology.[42]

This report repeated the recommendation of the Griffiths report that the United States should be the global leader for at least some major areas of science, and that it should strive to be among the world leaders for all major areas. The nation should also pursue international cooperation, especially for large and expensive projects. Review of research proposals and programs should be competitive, based on merit, and involve external evaluators.

Funding should focus on researchers and programs rather than institutions. To that end, investment in academic institutions would be preferable to extension of federal laboratory activities beyond their assigned missions. Federal laboratories serve important functions, but "should not seek new missions unless they offer both a critical advantage over other performers and the new mission better meets national needs" (p. 19).

The federal government should "encourage" the development of commercial technologies by the private sector, but it should fund them directly only in pursuit of government missions such as defense or "new enabling, or broadly applicable, technologies for which government is the only funder available" (p. 21).

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[41] Gary D. Krenz, ed., *The Future of the Government/University Partnership* (Ann Arbor: University of Michigan), p. 161-174; summarized elsewhere in this CRS report.

[42] Stine, telephone conversation.

Good management of science and technology is important. However, regulation imposes costs, and "federal agencies must strike a balance between the need for accountability and the burden of regulation." "Research and development should be well-managed and accountable but should not be micromanaged or hobbled by rules and regulations that have little social benefit" (p. 27).

Reshaping the Graduate Education of Scientists and Engineers

National Academy of Sciences, Committee on Science, Engineering, and Public Policy. *Reshaping the Graduate Education of Scientists and Engineers*. Washington: National Academy Press, 1995. 207 p.

Overview. An important aspect of U.S. efforts to improve economic competitiveness is the existence of a capable scientific and technological workforce. The emergence of the global markets deals not only in products and services, but in a highly trained human capital. However, there has been debate on whether U.S. colleges and universities are producing the graduates needed to power the American economy in an increasingly technological and competitive world. Widespread downsizing by the defense and aerospace industries, the end of the Cold War, off-shore improvements of research and development activities, newly revised immigration laws, private sector restructuring, and a slowdown in productivity and economic growth have translated into diminished job opportunities for some scientists and engineers. In addition, budget constraints in academia have limited the number of faculty and postdoctoral offerings.

In the fall of 1993, COSEPUP proposed a comprehensive study on the status of the graduate education and research training being offered in U.S. colleges and universities.[43]

Issues. Colleges and universities are facing the task of better educating graduate students in the scientific and engineering disciplines by restructuring their curricula to increase the versatility and employability of the graduates. It is held that scientists and engineers possess problem-solving skills that are broadly applicable in business and finance. However, selected doctoral degree programs are being challenged as too analytical and too oriented toward sub-specialities. An increasing number of employment positions for doctorate holders are found in industry rather than in academia, and are becoming more removed from the basic research skills that earned them their doctoral degree.[44] Critics have called for limiting enrollment in certain graduate programs and the phasing out of others. The nature of industrial work is changing and so the training offered by the many postdoctoral positions must be altered as well. Industry wants graduate students who will better meet their R&D

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[43] The project was supported by the National Science Foundation, the U.S. Department of Energy, and the Kellogg Endowment Fund of the NAS and the IOM.

[44] Raymond G. Greene, Barry J. Hardy, and Steven J. Smith, "Graduate Education: Adapting to Current Realities," *Issues in Science and Technology*, v. 12, Winter 1995-1996: 59-66; Linda Geppert, "Educating the Renaissance Engineer," *IEEE Spectrum*, September 1995: 39-47; and Mairin B. Brennan, "Education for an Era of Change," *Chemical & Engineering News*, v. 75, 17 March 1997: 43-52.

needs and compete effectively with their counterparts worldwide in a rapidly evolving job market.

The report stated: " The three areas of primary employment for Ph.D. scientists and engineers -- universities and colleges, industry, and government -- are experiencing simultaneous change. The total effect is likely to be vastly more consequential for the employment of scientists and engineers than any previous period of transition has been. . . . A broader concern is that we have not, as a nation, paid adequate attention to the function of the graduate schools in meeting the country's varied needs for scientists and engineers. There is no clear human-resources policy for advanced scientists and engineers, so their education is largely a byproduct of policies that support research. The simplifying assumption has apparently been that the primary mission of graduate programs is to produce the next generation of academic researchers. In view of the broad range of ways in which scientists and engineers contribute to national needs, it is time to review how they are educated to do so."[45]

Findings/Recommendations. The discussion of the major related issues focused on : the "right" number of science and engineering Ph.D.s -- including current employment situations and limitations of supply-demand models for forecasting science and engineering personnel needs; the issue of foreign students -- including support of foreign graduate students, where they go following graduation, and what are the effects, if any, on the U.S. labor force; time to employment; and information and analysis needs.

Following consideration of alternative approaches, COSEPUP presented a national strategy that was intended to emphasize both versatility and information. Several of those recommendations were as follows:

> To produce scientists and engineers who are versatile, graduate programs should provide options that allow students to gain a wider variety of academic and other career skills.
>
> To foster versatility, government and other agents of financial assistance for graduate students should adjust their support mechanisms to include new "education/training grants" that resemble the training grants now available in some federal agencies.
>
> To implement changes to promote versatility, care must be taken not to compromise other important objectives.
>
> Graduate scientists and engineers and their advisors should receive more up-to-date, accurate, and accessible information to make informed decisions about professional careers. Broad electronic access to such information should be provided.

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[45] *Reshaping the Graduate Education of Scientists and Engineers*, p. 3.

Academic departments should provide employment information and career advice to prospective and current students in a timely manner and should help students see career choices as a series of branching decisions. Students should not be encouraged to consider discrete alternative pathways when they have met their qualifying requirements.

The National Science Foundation and the National Research Council should continue to improve the coverage, timeliness, and analysis of data on the education and employment of scientists and engineers to support better national decisionmaking about human resources in science and technology.[46]

The Future of the Government/University Partnership

Office of the Vice President for Research, University of Michigan. *The Future of the Government/University Partnership* (Proceedings of the 1996 Jerome B. Wiesner Symposium). Ann Arbor: University of Michigan, February 26, 1996. 251 p.

Overview. This conference was held in hopes of moving toward a consensus on principles that would underpin a new partnership between the government and the nation's research universities. As stated in the conference's opening address, the major focus of those principles should be the "expectations that the public ... should have for the nation's research universities, and what the research universities need from the government in order to meet those expectations."

A report was issued prior to the conference (from the Committee on Institutional Cooperation) that arrived at a set of draft principles arranged in four thematic areas: Research and Scholarship in Support of the Nation's Well-Being; Education for the Next Century; Responsible Allocation and Utilization of Resources; and Stewardship of the Public Trust. The questions addressed by the principles are concentrated on the what universities can do to meet visions enunciated for these four areas. These draft principles were summarized in the conference's opening address.

Opening remarks were also made by Rep. Ehlers and Rep. Rivers about what each hoped to get out of the conference. Rep. Ehlers hoped it would serve to begin development of a new model for university/government relations. Rep. Rivers hoped it would address the direction in which the nation should move to ensure a productive academic enterprise and a healthy economic future.

The conference was a one-day event featuring speakers from government, university, and industry. The keynote address was given by Dr. Charles Vest, president of MIT. Sessions were entitled: The University in National Science and Technology Policy; Outputs: Research and Education for the 21st Century; and Inputs: Responsible Allocation and Stewardship of Resources.

Issues. Certain themes or issues appeared in several of the presentations and are presented here.

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[46] *Reshaping the Graduate Education of Scientists and Engineers,* op. cit., p. 78-88.

There was general agreement that changes in the relationship between the federal government and universities were taking place. These changes resulted from a number of forces including the decline in available funding resources, growing demands on universities to meet regulatory requirements, a growing skepticism by the public of the value of university research, and the lack of clear science and technology policy direction following the end of the Cold War. While there is general acceptance that universities have made significant contributions to the nation during the Cold War period, there does not seem to be the same feeling about the importance of university research to the nation's future. Many newer Members of Congress are challenging assumptions long held about funding university research.

The speakers agreed that funding university research was an important investment for the nation. The rate of return on R&D in general and university-performed research in particular has been shown to be high. That it is an investment compared to other calls on federal funds, however, is not accepted by all policy makers. Further, there are questions about how new knowledge generated in universities can most effectively be transferred to those parts of society where it is needed. How can partnerships be expanded to effect greater technology transfer?

Several speakers brought up the interaction between research and education. While most believed they are naturally supportive of one another, many felt that there are forces that are straining this synergy. The failure of the government to pay the full cost of research is causing universities to divert funds that otherwise would have gone to education. At the same time, the public is led to believe that research and education are often at odds with one another. Universities are viewed by some as not doing enough to contain costs to ensure access to all bright and talented students. Others argued that support of education on the K-16 level needs to be increased to expand the capacity of society to accommodate an increasingly complex world. Further, some felt that the education of the next generation of scientists and engineers is not getting the attention it needs.

Many of the speakers commented about the changing research policy environment. Policy goals for research seem to be undefined since the end of the cold war. The rationale as to where research goes next has not been clearly spelled out. Global economic competition has contributed to those changes. As a consequence, the innovation system fostered by the university/government partnership appears to be coming apart. The important mid-tier of the research hierarchy, pre-competitive research largely carried out by industry, has all but disappeared with industry concentrating on short-term, product-oriented research and universities continuing to focus on long-term, fundamental research. The flow of knowledge between industry and universities has been severely hampered as a result. Finally, efforts to balance the federal budget and reduce the size of government are having a profound effect on the research environment. While research funding has not suffered nearly as much as first feared, the future still appears bleak.

Several speakers brought up the role of the States. As many federal functions devolve to the States, it is reasonable to ask whether they should also contribute more to university research support. There can be an important role for the States in certain research areas. States could become part of the government/university partnership. Some argued, however, that it is not reasonable to expect much from the

States since they are already providing substantial amounts for general university support.

Findings/Recommendations. While the conference did not arrive at collective findings, there were themes shared by several speakers that served as findings and are presented here. These findings usually contained explicit and implicit recommendations, which are also included where appropriate.

The university/government partnership has proven to be of great value to the nation over the last several decades. That partnership was based on the premise that new knowledge was fundamental to the nation's well being and the most effective way to develop new knowledge was through federal funding of basic research at the nation's universities. In the future, new knowledge will be even more important for meeting the needs of society. Universities in partnership with the government and industry will continue to be a primary source of that new knowledge.

Without actions by both universities and the government, the partnership might falter in the future. Public support is critical to the partnership's success. At this time, public support is not strong. Without a better understanding of public concerns and taking steps to address them, universities are in danger of a further erosion of support. Universities need to be accountable. They must recognize the need for greater efficiency and cost control, strengthening peer review, and maintenance of the research infrastructure. Funding constraints will make it essential that universities share existing resources with all research performers including the national laboratories.

The federal government's responsibilities include a more predictable and flexible process for determining funding levels, particularly with respect to large projects. While the government has the responsibility for ensuring accountability and ethical conduct of research, administration of the regulations governing research performance, which now often acts as disincentive, needs to be more efficient and less burdensome. Finally, the federal government needs to move toward the goal of funding the full cost of research it supports.

Advocacy of the importance of university research appears to be lacking on the part of both universities and the federal government. All partners must do a better job of showing that science is in the common interest. Universities have an especially important role in engaging Congress in discussions about the importance of science and investment in research. A corollary is the importance of aggressively pursuing the transfer of new knowledge and the scientific process to help society achieve its goals. Without better links to industry, technology transfer will not be effective. Both universities and the government have responsibilities in enhancing this transfer.

Endless Frontier, Limited Resources: U.S. R&D Policy for Competitiveness

Council on Competitiveness. *Endless Frontier, Limited Resource: U.S. R&D Policy for Competitiveness.* Washington: Council on Competitiveness, April 1996, 145 p.

Overview. The Council on Competitiveness is a nonpartisan, nonprofit forum of chief executives from the business, university, and labor communities. The Council's primary mission is to set a national action agenda for maintaining U.S. leadership in global markets, technology innovation, education, and training that will raise the standard of living of all Americans. The Council was established in 1986 and is supported by private contributions, foundations, and other granting organizations. The Council regularly produces reports benchmarking U.S. competitiveness in general and in specific technology areas.

Issues. This report discusses the changing global environment in science and technology, the challenges these changes create for the U.S. R&D establishment, and what institutions in each of the three sectors (government, private, and academia) need to do to meet those challenges. The report also provides more specific discussions on six industrial sectors -- aircraft, automotive, chemicals, electronics, information technologies, and pharmaceuticals. The following discussion highlights the general part of the report.

Findings/Conclusions. The global environment in science and technology has been undergoing fundamental change. The Council described four changes that impact the structure and policies of the U.S. R&D establishment -- tighter budgets, a shift toward nearer-term research, globalization, and changes in the innovative process itself.

The R&D establishment in the United States is undergoing budgetary pressures that are not likely to be relieved in the near-term. In 1986, the United States had the highest R&D intensity (R&D expenditure/gross domestic product (GDP) equal to 2.8%) in the industrialized world. In 1995, the R&D intensity of the United States dropped to 2.4%. The Council estimated that in 1996, the intensity could drop to 2.2%. Federal support for research and development peaked in 1989 in real dollars and is expected to continue to decline as the government seeks to balance its budgets. Private sector support for research and development has been relatively flat since 1988. Although there is some expectation that private sector investment in research and development will increase soon, it is not clear whether it will increase enough to offset declines in federal support.

While the Unites States still spends more on research and development than any other country, and more than many of them combined, the United States has fallen behind in some areas. Also, in terms of non-defense R&D intensity, the United States trails Japan and Germany. The Council also noted that if Japan doubles its governmental R&D expenditures by the year 2000, as it has said it will try to do, it will spend more than the United States on non-defense related research and development. Flat or declining budgets mean that the United States must make painful choices about what it will fund.

Related to this decline in research intensity is a shift in emphasis to research with shorter time horizons. This shift is driven primarily by industry as it has sought to concentrate on core capabilities. Many firms have either done away with central laboratories or support more of their central laboratory research and development with funds from business units. Firms still support longer-term research, but rely more on government laboratories or universities to do it. This is also affecting the time horizon of those institutions.

Research and development is becoming increasingly global. Advances in science and technology are not only coming from traditional sources in the industrial world (e.g. Germany and Japan), but also from new sources (India, Israel, China, and other Asian countries). U.S. firms are increasing the amount of research and development bought or conducted overseas. Foreign firms are increasing the amount of research and development bought or conducted in the United States. This trend presents both challenges (new competitors) and opportunities (new partners). The Council suggested that the United States should encourage as much R&D to be done in this country as is possible, including U.S. multinationals that might find benefit in doing research overseas.

The innovation process itself is changing. Technologies are becoming more sophisticated and complex, requiring interdisciplinary teams to conduct research, development, and innovation. Also, product cycles are shortening, putting a premium on speed and incremental improvements. This presents a challenge to find the resources to continue conducting the long-term research needed to discover and exploit more revolutionary advances.

The Council came to two primary conclusions (called findings). First, increased partnerships can help meet the challenges of the changing environment. Government, the private sector, and universities must continue to find ways to form partnerships, not only with each other, but with their counterparts in other countries. The second primary conclusion was that the current debate over what role government, industry, and academia should play in the nation's research and development enterprise is polarized, detrimental to making progress, and based on an outmoded distinction between basic and applied research. The complexity of technologies today does not allow for a clear distinction between basic research and applied research. Nor is the linear model for innovation, which describes innovation as following an orderly flow from basic research to applied research to product development, adequate to describe the real process by which innovation occurs.

Recommendations. The Council made two general recommendations, although it does not identify them as such. The first is that all institutions within the three sectors must prioritize by concentrating on their core missions and capabilities and then make sure their internal policies facilitate partnerships in order to leverage their investments as much as possible. The report goes into a little more detail on what each sector needs to consider.

The second recommendation is to restructure the framework upon which the roles of government, industry, and universities are determined. It suggested doing away with the notion of basic and applied research as an organizing concept and go instead to the relative time-horizon and the amount of risk associated with particular research and development (see the figure below). Government should support longer-term research (basic or applied) with higher risk — research that needs to be done, but which private industry is unlikely to do without government support.

TYPE OF RESEARCH	RESPONSIBILITY FOR CONDUCTING RESEARCH	
	Primary	**Secondary**
Short-term/Low-risk	Industry	Not-for-Profit
Mid-term/Mid-risk	Industry/Government	Universities
Long-term/High-risk	Universities/Government	Government/Industry

The council stated that industry is leading the way in focusing its efforts and facilitating partnerships, at least among industrial firms, and perhaps with universities. But to maintain momentum, industry needs to increase its contribution to research and development. Industry, too, still needs to take better advantage of what government laboratories and universities have to offer.

The federal government has had a harder time focusing its efforts, primarily due to political pressure to keep current programs going. In a rather bold statement, the Council suggests that government must "meet its long standing obligation to stimulate civilian research." Among its core missions, along with national defense and public health, should be the stimulation of research that is required to keep the United States economically competitive. Government, industry, and academia should select these technologies together. The Council notes that DOE, NIH, NASA, and NSF have made efforts to be more responsive to industry needs, but that these programs are relatively small and politically vulnerable.

The federal government also needs to redefine the mission of its laboratories. One-third of the federal investment in R&D goes to federal laboratories. DOE laboratories account for about one-quarter of that, most of the rest goes to DOD, NASA, and NIH. While stating that federal laboratories should be preserved, the Council recommended that their missions be narrowed, that unnecessary overlap be eliminated, bureaucratic oversight reduced and that a culture of partnering be more firmly established. The Council noted that these are not new suggestions, but that no consensus has emerged on how to do them. The Council did not make any specific recommendations.

The federal government also must maintain its investment in university research. In 1970, the federal government provided universities with 70% of their R&D support. By 1993, this dropped to 53%. Universities are the key to basic research, they attract industrial laboratories and investment, and they train future scientists and engineers. However, maintaining investment should not necessarily mean expanding the number of research programs.

The Council made three other more specific recommendations to improve the environment for innovation. Government needs to reduce those regulations that raise the cost of innovation (for example, some regulations of the Food and Drug Administration associated with clinical trials). Government should also eliminate the Treasury Department's regulations that require U.S. multinational firms to treat a portion of their domestic research and development expenses as having been conducted abroad. And, the federal government should make the R&D tax credit permanent.

Cutting costs will be particularly hard for universities after of 50 years of significant growth. The tasks of universities are made more difficult by their having conflicting missions. A university's primary mission is to educate. However, they also receive industrial or federal funding to do research. They are increasingly being relied upon to do the country's long-term research, but are being contracted to do more shorter term research. Also, while universities are supposed to be the storehouse of public knowledge, more and more of their research is considered proprietary, either by the firms providing the funds or by the universities themselves. Finally, the national R&D establishment must rely increasingly on interdisciplinary efforts, but university tenure policy, department structure, and program offerings are becoming more specialized. Although federal government research funds are declining, universities still rely heavily on them and are vulnerable to further cuts in federal R&D spending. Universities need to define their own priorities more clearly and reassess their links to industry and the federal system.

Evolution of U.S. Science Policy

Harvey Brooks. Evolution of U.S. Science Policy. *Technology, R&D, and the Economy*. (Edited by Bruce Smith and Claude Barfield) Washington: The Brookings Institution and the American Enterprise Institute for Public Policy Research, 1996: 15-48.

Overview. This book is a publication of papers given at a conference sponsored by the National Science Foundation and hosted by the Brookings Institution and the American Enterprise Institute in October 1994. The aims of the project were to assess the role of R&D in the economy, to identify promising new areas of research and analytical approaches, and to contribute to the public debate as the nation seeks to define a new framework for its R&D policies in the post-Cold War era.

Issues. The primary issue addressed by Dr. Brooks was whether is it desirable and feasible for the federal government to take a more explicit role in directing science and technology resources to meet specific social objectives (in this case, to improve U.S. economic competitiveness and performance).

Findings/Conclusions. Dr. Brooks did not answer the above question directly but puts the question in the context of a long historical debate about the feasibility and desirability of planning the agenda of the science and technology enterprise to meet explicit societal or economic goals. In the 1930s, Michael Polyani and J.D. Bernal had this debate. Polyani's position was that society could benefit most efficiently over the long run by giving the science and technology community a large degree of autonomy to set its own research and development agenda. Bernal argued that the enormous potential benefits that science and technology held for society could only be realized through a publicly discussed and debated flexible plan involving government and many other representatives of society.

Dr. Brooks described what he considered to be different phases of science policy in the United States, defined in part by shifts in emphasis from one of these models to the other. He argued that the United States was currently (October 1994) in a phase where the Bernal model is in ascendancy. The key social objective now guiding U.S. science and technology policy (aside from public health which has enjoyed continuous and increasing government support since the 1950s) is economic competitiveness and performance. Dr. Brooks cites as evidence of this latest shift the Clinton/Gore position paper entitled *Science: The Endless Resource*. Taking off from the Vannevar Bush report entitled *Science--The Endless Frontier*, the Clinton/Gore position paper suggested that government's role is not just to create new knowledge, but to ensure that it is accessed and used to better society.

Dr. Brooks identified nine issues associated with this shift toward the Bernal model and the social objective of improving economic performance that were as yet unresolved.

- National laboratories, especially the large DOE laboratories, probably are better positioned than universities to meet the social objective of improving economic performance. They have experience in mobilizing high-level interdisciplinary teams to solve specific problems. Also, they do have some manufacturing experience upon which to draw. Universities, however, which typically explore even applied-oriented problems in more depth, might actually provide more net social benefits through the additional knowledge generated by doing that.

- What are the implications for university priorities and policies which respond to calls for greater synthesis and diffusion of science and technological knowledge rather than just the creation of that knowledge? Giving greater weight to knowledge synthesis and dissemination implies everything from radical changes in instruction methods to development of hardware and software as aids to knowledge access and retrieval. The practicalities of doing this at universities or at intermediate organizations have not been worked out.

- What will or should be the impact of increased interest in economic performance on participation of foreign entities in government-supported research and development programs? The productivity of the U.S. technical work force has become steadily more dependent on students, scientists, engineers, and skilled practitioners from all over the world. However, there are many inconsistencies in the legal mandates of new programs regarding the participation of foreign nationals and foreign-owned companies. A "reverse" brain drain, where more foreign nationals are returning to their native countries than are coming here, makes any U.S. techno nationalism even more counterproductive. The issue can no longer be treated by the scientific and technical community with benign neglect.

- What should be the ground rules, criteria, and procedures governing State and federal agencies' involvement in international cooperative research and education programs? The United States is acquiring a reputation as an unreliable international partner. Declining federal R&D budgets will likely make this issue worse.

- If job growth is the ultimate goal, what institutions and what technologies are the best ones to support, and by what processes will this goal be translated into concrete and reasonable objective project selection criteria that command widespread support in the community? The federal government has yet to develop a clear rationale for public support of projects in collaboration with industry for the benefit of economic development and job growth. What are the public benefits? Sometimes higher profits and jobs are considered to be the public benefit.

- How can it be ensured that government funds for research and development are not simply displacing private funds for research and development? In trying to assess this, there should be realistic allowances for displacing potential private investment. Such allowances might include better diffusion and exploitation of the knowledge generated by a cooperative program.

- What are the long-term implications of this emphasis on economic performance on the allocation of resources to universities, national laboratories, non-government non-profit laboratories, and private laboratories and to what extent should resources be channeled through political subunits (i.e. State, regional, or local governments)? Except for a short-term increase in the share of federal R&D investment going to universities in the 1950s and 1960s, the relative allocation of that investment between the different institutions have varied little since the end of World War II. Is that allocation still appropriate? Will increased emphasis on economic performance and cooperative research with industry alter the allocation?

- Will emphasis on economic performance split and disperse (not geographically, but administratively) the technological capacities now accumulated in national laboratories? Are the large centralized organizational structures of national laboratories appropriate to the economic performance mission. Without a well-thought-out restructuring plan, laboratories may simply be closed and the skills and experience scattered.

- What does a rapid downsizing of the federally-funded R&D system mean for institutions whose primary mission is to train and educate new scientists and engineers, and what changes are needed in the nature of their training? Even if funding to universities is sustained, if graduates cannot find jobs outside academia, where will they go? It is unlikely that the private sector can or will absorb those people quickly because of the different nature of the work typically done at national laboratories as compared with private sector laboratories.

Recommendations. Dr. Brooks did not offer any specific recommendations, but he did caution that the debate between “open-ended” university research versus “appropriable science” cannot and should not be resolved. Rather, he argued that society benefits most from the tension and interplay between the two.

Investing In Innovation, Toward A Consensus Strategy for Federal Technology Policy.

Lewis Branscomb et al. *Investing In Innovation, Toward A Consensus Strategy for Federal Technology Policy*. Cambridge: Harvard University, Center for Science and International Affairs, April 24, 1997, 26 p.; and Lewis Branscomb et al. Technology Politics to Technology Policy. *Issues in Science and Technology*, v. 13, Spring 1997: 41-48.

Overview. The Harvard report is a result of a project undertaken by the Science, Technology and Public Policy Program at Harvard University which was sponsored by the Competitiveness Policy Council, a bipartisan federal advisory commission. Many of the recommendations originated from a diverse set of experts who participated in a policy conference held jointly by Harvard and the Competitiveness Council in Washington, D.C. on November 18-19, 1996. The Harvard report (which is an interim report), as well as the *Issues in Science and Technology* article, reviews the debate that emerged between the Republican Congress and the Clinton Administration regarding the appropriate federal role in fostering technological innovation. According to the authors, much of this debate has been based upon the "linear model" which depicts technological innovation as a distinct three-step process involving basic research, applied research, and development. However, the authors noted that the experts who have studied this process contend that technological innovation is a much more complicated process. The report suggested that the President and Congress should abandon their attempts to differentiate between basic and applied research. The authors concluded that a single overall science and technology policy must give way to policies geared at better defining the roles that industry, government (both federal and State), and universities can play in contributing to the nation's technological innovation. The report concluded by outlining six key principles the authors believed could help end the debate between the Administration and Congress and help revise America's technology strategy during the next four years, as well as into the 21st Century.

Issues. When President Clinton took office in 1993, he called for significant funding increases for the Advanced Technology Program (ATP), as well as other federal cost-shared programs with the private sector, including the Partnership for a New Generation of Vehicles, the Defense Department's Technology Reinvestment Program, and later the Environmental Technology Initiative. According to the report, when the Republicans took control of Congress many Members in the majority party voiced strong opposition to the President's technology initiatives. They called for the elimination of the ATP, as well as other similar technology programs. The authors contend that it is fortunate that the most strident voices did not prevail, because to reverse course to that extent could have had "disastrous consequences" for the United States. The report stated that, "the partisan conflicts and ideological rifts of the past few years, while helping to clarify the terms of the debate over public investment in research, have made it difficult to develop a much needed consensus on the nature and scope of government investment in and promotion of innovation." (Harvard, p.4)

However, the report noted that the end of the Cold War, the decline in corporate support for long-term, high-risk research, growing international economic competition, and declining federal R&D budgets, provide the Administration and Congress with a unique opportunity to set a new course regarding the appropriate role of the federal government in fostering technological innovation. The principal guide to government's role in helping the nation innovate is rather straight forward: "Government should try to help U.S. firms respond to the competitive challenge of a fast-changing global marketplace and should be able to do it without meddling in domestic markets, or favoring selected competitors." (*Issues*, p. 42)

While the reports acknowledged that ideological difference may be difficult to overcome, there has been strong support for government research investments where private institutions under-invest because they cannot capture the full benefits, but the return to society is greater than the public cost. This has been the rationale for public support of basic research where the benefits are widely diffuse. Further, the report noted that, when political debate divides the world of R&D into basic scientific research on the one side and lumps everything else from applied research (or basic technology research, definition to follow) and product development together on the other side, sight is lost of a huge and important gray area in between: need-driven creative research into new kinds of materials, new processes or ways of exploring and measuring, and new ways of doing and making things. (Harvard, p.8)

Findings. The authors concluded that innovation is the product of intellectual creativity and broad based collective efforts. They argued that the process of innovation grows more complex as countries around the world join in a global effort to create and exploit new possibilities. The authors found that the United States requires a carefully-crafted, broadly-supported approach to this global challenge. The report concluded that the current single, overall technology policy must give way to a comprehensive, sophisticated technology policy, based on a widely-shared consensus, that is continually evaluated and adjusted to meet changing competitive markets.

Recommendations. In that light, the report outlined six principles which reflect the view that the most appropriate and effective role for the federal government is to ensure that organizations and individuals have the knowledge, skill, and incentives to generate private investment in innovation. The report stated that these principles are entirely consistent with the government's central economic strategy to encourage savings and investment rather than driving consumption.

Principle 1: Encourage Private Innovation. Leverage private investment in innovation to spur economic growth, improve living standards, and accomplish important government missions by creating incentives for and reducing barriers to technology development and research-based innovation.

The central thesis of this recommendation was that the engine of innovation and productivity growth is in the private sector. Wherever possible, the authors argued, the pursuit of technology policy should favor the use of market mechanisms, such as tax incentives, and creating markets for non-market entities, such as tradable permits for sulfur emissions, over direct government funding of R&D. However, policymakers should realize that private firms under-invest in longer-range research, and in research to meet public purposes. Therefore, federal interventions must encourage private investment in technology development, rather than substitute for it. The report contended that cost sharing arrangements should be a basic precept of federal technology initiatives, where both public and private value is produced. Cost-sharing requirements might be reduced in those cases where firms allow or even encourage the technology to be widely shared. However, the report stated that industry's cost-sharing requirements should be raised as the investment area is closer to the market.

Principle 2: Emphasize Basic Technology Research. Focus direct government investment in science and technology for economic purposes on long-range, broadly useful research in basic technology as well as basic science -- both of which produce benefits far in excess of what the private sector can capture itself.

In terms of direct or matching support of federal research, the report recommended the government continue to focus on traditional basic scientific research, as well as "basic technology research" both of which produce benefits far in excess of what the private sector can capture itself. Basic technology research includes activities which involve investigating fundamental processes (a complement to basic scientific research) of specific technologies such as blue lasers, biosensors, and the wearable computers. Such activities usually start "early in the innovation process and lead to knowledge that is often non-proprietary and widely diffusible though clearly on course . . . for industrial applications. Basic science and basic technology research are inextricably linked and dependent upon one another." Further, companies have become more reluctant to put resources into basic technology research that is long term and high risk, or both, even though this research could eventually pay handsome returns to society as a whole. The report noted that more narrowly-targeted or short-term research, with clearly defined goals, like product and process development, should be funded by the intended beneficiary, which might be a private firm or, in the case of technology needed primarily for government purposes, by a federal agency.

The report also contended that public-private technology partnerships should be structured so that it is clear how the results will reach a broad range of users and benefit the public at large. This implies using consortia of private firms, universities and national laboratories in almost every case, except where the government is the customer for the end product. The report noted that a mixture of institutional performers may be best, since industry, universities, and national laboratories have their unique ways of ensuring that new work reaches a variety of potential users.

Principle 3: Make Better Use of Available Technology. Promote effective use and absorption of technology across the economic spectrum, with special attention to the role of higher education and the states in technology diffusion.

Essentially, this recommendation focused on the need for stronger federal and State efforts to improve the transfer of technology to the private sector, primarily smaller firms, primarily because many small firms have a limited ability to choose among technologies and to make effective use of them. The Federal government, working closely with States and regions, should develop closer links between technology policy and work-force training and development. This will help spur the diffusion and use of technology and create strong links between technology and the creation of high-wage and high-skill jobs.

The report noted that the National Institute of Standards and Technology (NIST) Manufacturing Extension Partnership (MEP) program is an effective model of federal-State partnership in technology diffusion and regional economic development. The report also recommended that the States should play a role in shaping NIST's Advanced Technology Program (ATP). For example, ATP should no longer focus its grants to a single company, but should focus it resources on establishing multi company consortia so that groups of companies can benefit from new ideas, such as techniques for creating new polymers, materials for semiconductors, and new systems for managing information.

Principle 4: Use All Policy Tools, Not Just R&D Support. Utilize the full range of relevant policy tools (e.g. tax incentives, regulatory reform, standards, and intellectual property rights), recognizing that different industries, technologies and regions may call for different mixes of these policy tools.

A "one size fits all" technology policy is almost certain not to be successful. Rather, the report argued, every industry is different and government agencies must be sensitive to these differences, which calls for different policy tools and different mixes of science, technology, and systems research. For example, strong patent protection is essential to business success in pharmaceuticals, but less so in the computer industry, where most large firms are cross-licensed internationally. Biotechnology companies draw directly on forefront basic research, while chemical and materials firms are more dependent on advanced process technology.

Besides directly funding R&D, the federal government should support an array of indirect incentives to help foster technology development and diffusion including: (besides those mentioned above) facilitation of standards development; federal procurement; antitrust law and competition policy; and consensus building and policy analysis , like that performed by the defunct Office of Technology Assessment. For example, direct federal funding for the National Information Infrastructure (NII) is not as important as the role the federal government is playing in ensuring that regulatory hurdles are cleared and technical projects are funded so that programs such as the Second-Generation Internet can be useful for both public and private sector customers.

Principle 5: Leverage Globalization of Innovation. Encourage U.S. led innovation abroad as well as at home, and enable U.S. firms to get maximum benefit from world-wide sources of technical knowledge.

Essentially, U.S. technology policy must encourage and facilitate globalization and transnational collaboration, not impede it. The United States must learn to cooperate as well as compete, given the rapidly growing technical assets in other countries, assets which in many cases are the product of public investments. The report noted that resolving trade conflicts tends to get more public attention than investments in transnational collaboration and cooperation in the development of new science and technology, which often brings even larger benefits. According to the report, the Global Information Infrastructure (GII), where U.S. firms and institutions enjoy a commanding lead today, is an excellent example of the need for U.S. leadership in developing a harmonious international environment.

Principle 6: Improve Government Effectiveness. Make government a stable and reliable partner in a long-range national research effort through more effective institutions for policy development, strong and stable bipartisan support, and stronger participation by the states in policy formation and execution.

The final recommendation called for strong and stable bipartisan support for technology policy primarily because of the long-term nature of most government investments and the policies recommended in this report. American science and technology thrives because it is supported by a pluralistic system. There are many sources of support, many types of performers, and a maze of linkages among funders, performers, and users of science and technology. Further, there is not, and should not be, a centralized technology policy process that undermines the value of pluralism. Technology policy should be explicitly experimental, continually adjusted, and informed by access to expert advice.

The Executive Office of the President must provide the locus for linking broad national policy objectives, such as economic and security policy, with the technology agenda. Congress, on the other hand, must be an active, but patient and sophisticated participant. Congress also has a central decision-making role, adjudicating among technology policy experiments. Policies that fail should be terminated; policies that succeed must be maintained or expanded. However, most importantly, policy experimentation must be tried for a sufficiently long time and under sufficiently reasonable conditions in order to be judged. The authors noted that the Administration, in its first term, may have moved to expand its technology policy initiatives too rapidly, while Congress may have moved too fast to hamstring or de-authorize these initiatives. The authors hoped that all sides will show more patience during the next four years.

The report also has an appendix which contains a number of policy recommendations, including calling for the National Science Foundation to support basic technology research, establishment of an Information Technology Policy Council under the White House National Science and Technology Council, a strengthened technology advisory role for the White House National Economic Council, an overhaul of the Environmental Protection Agency's Environmental Technology Initiative, and greater utilization of the Critical Technology Institute, within the Office of Science and Technology Policy.

Pasteur's Quadrant: Basic Science and Technological Innovation

Donald E. Stokes. *Pasteur's Quadrant: Basic Science and Technological Innovation* Washington: Brookings Institution Press, September 1997. 175 p.

Overview. This book analyzed the basis of post-World War II science policy in the United States. The author first described the policy framework as it was developed by Vannevar Bush in his 1945 report, *Science -- The Endless Frontier*. He then assessed how well that framework described the federal R&D funding system that emerged after the war. After a discussion of the historical basis for the Bush research model, the author proposed a new model that he claimed more accurately portrays how R&D is performed. Next he examined how this new model can be the used to restore the compact between government and science. The book concluded with a discussion of the role of scientists in developing science policy.

Issues. The Bush report set forth models describing basic and applied research, and the connection between basic research and technological innovation that became the foundation of U.S. post-war science policy. Bush's first model classified research in terms of a one-dimensional, linear spectrum defined by the motivation of the researcher. At one end is curiosity-driven basic research motivated by the desire to seek new understanding and knowledge about nature,. At the other end is use-driven applied research motivated by the desire to use that knowledge in a practical way. The more one is concerned about application or use of research, the farther one moves from basic research toward applied research. Bush's second model proposed that the new knowledge spawned by basic research will eventually be converted through applied research and development in a linear, sequential fashion into technological innovations that lead to economic growth and other societal benefits.

Despite the broad acceptance of a model separating basic research from any applied goals, actual experience argues that it is unfounded. Much of the fundamental knowledge generated in the last century has been the result of basic research with specific applications in mind. Basic research can be both use- and curiosity-driven.

Bush's second canon, the linear model of technological innovation, is also suspect. First, it is too simple. The connections between basic knowledge and innovations, when they exist, are much more complex than a simple, linear flow. Second, not all innovation is derived from science. Often innovation will arise by "tinkering" with existing technology. Third, not all connections, when they do exist, flow from science to technology. There have been numerous cases where science developed to explain already working technology.

Findings. While belief in the Bush framework has guided science policy over the last 50 years, it has come under increasing attack in the last several years as many no longer believe that a "heavy investment in pure, curiosity-driven research will by itself guarantee the technology required to compete in the world economy and meet a full spectrum of other societal needs." Reconsideration of the framework is gaining adherents as interest in applying science to economic growth increases.

The problem is that a linear, one-dimensional spectrum running from basic to applied research is inadequate to the task. A new model can be formulated as a box with four quadrants. The quadrants are defined on one axis according to whether the research is use-inspired or curiosity-inspired, and on the other axis by whether it seeks fundamental knowledge or not. The upshot is the appearance of a new category — or quadrant — that is characterized by basic research driven by a desire to solve a practical problem. It is called Pasteur's quadrant because much of the basic research he carried out that advanced fundamental understanding of the biological sciences was motivated by trying to solve specific public health problems. Two other quadrants correspond to the Bush framework in that they characterize pure, curiosity-driven basic research and applied research for entirely practical ends. These are called Bohr's quadrant and Edison's quadrant respectively, because of the type of research carried out by each. The quadrants are not isolated from one another, however, and there is a complex array of possible linkages between them.

A new model of technological innovation, is also needed. The new model must account for two trajectories: the path of technology innovation leading from existing to new technologies, and the path of scientific understanding leading from existing to new knowledge. The two paths, while independent, are loosely coupled. At times they will influence each other quite strongly with the interaction moving in either direction. Quite often, the linkage is use-inspired, pure science, although there are other connections as well. The connection between science and technology is more completely described in this model showing that each can drive the other, but that the most important drivers are usually internal to the individual paths.

Recommendations. The post-war compact between science and the government appears to have fallen apart, as a result of three developments.

1. *End of the Cold War*. Perhaps the major factor in establishing and sustaining the compact was the desire to invest in science in order to maintain a technological edge over the Soviet Union. With the end of the Cold War, that stimulus no longer exists.

2. *Integration of the World Economy*. Some countries — notably Japan — have become very competitive in a number of high-technology areas without having a strong science base. As a result, many have questioned the concentration on pure research if the major driver of economic growth is rapid technological innovation.

3. *The Budgetary Legacy of Fiscal and Economic Policy*. The pressures brought on by efforts to reach a balanced federal budget in 2002 have made it clear that R&D funding will likely decline in constant dollars.

Recommendation I

A recognition of the reality and value of use-inspired basic research can help develop a firmer S&T policy. The compact can be renewed by joining the "inspiration basic science can draw from unmet societal need with the high value the policy community places on the problem-solving capacity of science" (p. 107).

Recommendation II

A process that brings together the "scientific judgements of research promise and political judgements of societal needs" (p. 108) can realize a new compact if that process adheres to the following:

1. "A system for appraising scientific promise and social value at the project level should enlist the insight of the working scientist into the nature of the social goals on which his or her research bears" (p. 118).

2. Scientists should not be excluded from the discourse that seeks to make judgements about social value or else the creative insight of the scientist for defining and judging social goals would be lost, and a funding system with the potential for great conflict would be created.

3. "Public funds invested in use-inspired basic research will bring a greater return if they are allocated among alternative projects through peer review by panels

capable of judging scientific promise and the societal benefit from the resulting scientific knowledge" (p. 123).

Recommendation III

The National Institutes of Health, more than any other agency, has put the use-inspired basic research model to effective use in defining its research agenda. NIH has accommodated policy direction for more attention on specific diseases primarily by expanding use-driven basic research.

"In the evolving arrangements for funding use-inspired basic research, attention should be given the possibility of replicating the NIH model in other areas where research promise is felt to match societal need, with the field of environmental science a leading candidate" (p. 144).

Recommendation IV

The National Science Foundation could provide a leadership role in advising the Administration and Congress on science policy. If so, NSF must "make it clear to Congress that the key to turning the power of basic science to national needs is .... to build agendas of use-inspired basic science, funded by agencies across the government, that bear on the nation's needs" (p. 154). The need to bring science to bear on national needs is still important if based on the premise that good basic research can be performed even if it is directed toward "practical ends."

Analysis of Major Cross-Cutting Themes

Introduction

The ten reports summarized in the preceding section,[47] although they cover many issues and resulted in hundreds of recommendations, represent only a fraction of the efforts expended on assessing U.S. science policy. They were selected because they cover the subjects of federal R&D budgets and priorities, and university-government-industry issues. They do not cover in detail many important topics or issues of current S&T policy, including, for example, international S&T, federal laboratory reform, assessment of the peer review system, or proposed changes in the role of the National Science Board in making recommendations to the president on national science policy.

Some additional projections and issues, although not specifically discussed in the ten reports, are assumed or implied. For example, the nation has moved far beyond the era of the Bush report when the United States was the unchallenged S&T power in the world. Consequently, it was generally implicit in the reports that were summarized that priorities for national science and technology should be determined in both a domestic and international context. Likewise, constraints on the federal R&D budget generally were treated as likely to continue.[48] The reports revisited many of the themes that have arisen time and again in the S&T policymaking efforts of the last 45 years, such as legislative and executive branch S&T reorganization and

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[47] For ease of reference, abbreviated citations are given here. Full citations are given in the report summaries in the preceding section.

OTA. *Federally Funded Research: Decisions for a Decade*. 1991.

Carnegie Commission on Science, Technology, and Government. *Science, Technology, and Government for a Changing World*. 1993.

NAS. *Science, Technology, and the Federal Government: National Goals for a New Era*. 1993. (The "Griffiths report.")

NAS. *Allocating Federal Funds for Science and Technology*. 1995. (The "Press report.")

NAS. *Reshaping the Graduate Education of Scientists and Engineers*. 1995.

University of Michigan. *The Future of the Government/University Partnership. 1996*.

Council of Competitiveness. *Endless Frontier, Limited Resources: U.S. R&D Policy for Competitiveness*. 1996.

Harvey Brooks. Evolution of U.S. Science Policy. *Technology, R&D, and the Economy*. 1996.

Lewis Branscomb et al. *Investing In Innovation, Toward A Consensus Strategy for Federal Technology Policy*. 1997.

Donald E. Stokes. *Pasteur's Quadrant: Basic Science and Technological Innovation*. 1997.

[48] Although federal civilian R&D funding has increased in constant dollars since 1993, CRS estimates, based on the FY1998 Budget Resolution, indicate a 9% decrease in federal civilian R&D funding from FY1997 through FY2002.

S&T priorities, but in the context of the current problems and opportunities facing the nation.

This section identifies major cross-cutting themes that emerged from the ten selected reports. All noted that significant national and international changes are affecting the nation's S&T system. They discussed three kinds of responses: new mechanisms for determining S&T goals, priorities, and budgets; new models of research, development, and innovation, and refinement of the roles of government, industry, and academia in each; and changes in university research and the university/government relationships. These points are discussed in the following sections.

Significant Changes Affecting the Nation's Science and Technology

A number of major changes are occurring in the world at large and in science and technology. The end of the Cold War is one such major change, as is increasing international economic and scientific competition. These changes provide both opportunities and problems for the U.S. S&T system.

The major impetus, for example, of the Carnegie Commission on Science, Technology, and Government study was, for society, the "profound difficulty of meeting the challenge of accelerating scientific and technological developments,"[49] as well as the challenges of economic growth, sustaining the environment, and living peacefully in the post-Cold War world. Because of such changes, the summary report called for a "transformation" in the way science and technology policymaking is organized in all branches of government, as well as in nongovernmental organizations.

The 1993 "Griffiths" report of the Academy stated that major changes over the last decade, including the end of the Cold War, the information revolution, and the increasing intensity of international economic and scientific competition already had altered the framework for U.S. science and technology. The "Press" report of the Academy two years later also noted these same changes. The Council on Competitiveness report discussed four changes that affect the U.S. S&T system, including "globalization" of R&D, tighter R&D budgets, and the changes in research and innovation noted in the section on "new models," below. The Branscomb report identified these changes as providing an opportunity for the government to determine its appropriate role in technological innovation through, for example, its policies on transnational collaboration. The Stokes book identified these changes as contributing to the weakening of the post-World War II compact between science and government in this nation.

New Mechanisms for Determining S&T Goals, Priorities, and Budgets

The reports made many recommendations as to how the U.S. S&T system, and specifically the U.S. government R&D establishment, can respond to the major

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[49] Quotations, unless otherwise noted, are taken from the report summaries in the preceding section; citations are not repeated in this section.

changes occurring in the world and in science and technology. These recommendations centered on the need for new mechanisms to determine national S&T goals and priorities and federal R&D budgets. The reports discussed aspects of national S&T policy that are contentious, including the proper role of government in guiding the nation's S&T for social purposes, a specific case being national technology policy.

The OTA report concluded that mechanisms for federal S&T priority setting need to be improved because, for example, criteria used in selecting research areas generally are inadequate, there is no mechanism to evaluate research progress toward many national objectives, and human resources and regional and institutional capacities need to be considered along with scientific merit and mission relevance. The Griffiths report also raised questions about the historical assumption that S&T is making needed contributions to national objectives in some cases, specifically in regard to some current medical and environmental research. The OTA report addressed the need to better understand the costs of conducting research, which have increased faster than inflation, and concluded that R&D data collection and analysis (including the results of research) need to be improved to aid in decision making. The OTA report's focus was on cooperation across federal agencies.

The Griffiths report made recommendations, repeated in the Press report, that the United States should aim at being the world leader in some major areas of science and "among the leaders" in all major areas of science. The report also recommended steps be taken to make the federal budgetary process for science more "coherent."

The Press report responded to a congressional request to examine the criteria to be used in evaluating the balance in federal research and development funds and between R&D institutions in an S&T system which evolved during a time, now past, of funding growth and mission expansion. It recommended that the government establish a Federal Science and Technology budget, eliminating from consideration activities like systems development in DOD, DOE, and NASA and that the entire FS&T budget be presented by the President and considered by Congress in its budget allocation process. The Academy is continuing its work on how to apply the FS&T concept to decision making.

The proceedings of the conference held at the University of Michigan on the future of the government/university partnership noted that the changes occurring in the historic government/university partnership are, in part, due to the lack of clear federal S&T policy direction since the end of the Cold War.

The Brooks article discussed the historical debate about whether society benefits most by giving the S&T community a large degree of autonomy to set its own R&D agenda, or by public participation in, and governmental planning of, the nation's R&D agenda. Arguing that the second "model" is in its ascendency, and that the key social objective guiding the nation's S&T policy today (aside from public health) is economic competitiveness and performance, the article outlined nine unsolved issues that must be addressed if this social objective is to be achieved, including the changing relationships among government, industry, and academia.

The Branscomb report called for a carefully crafted, comprehensive, sophisticated, and adaptable technology policy to replace the current "one size fits all" technology policy. It sets forth six principles incorporating what it believes to be the government's appropriate role in technology policy.

Defining New Models for R&D and Innovation

Since at least from the time of the Bush report, basic and applied research, and innovation, have been considered to be connected in a linear fashion. Questions were raised in the reports analyzed here, however, that go to the very heart of what may be termed the standard model of R&D and innovation. Several recommendations for a new understanding of these terms and new models of their relationships were offered.

Stokes proposed a new model that he claimed more accurately portrays how R&D actually is performed than does the Bush model of curiosity-driven basic research and applied research entirely for practical reasons. Stokes proposed a new model that allows for basic research driven by a desire to solve a practical problem. Such a model should be used in selecting areas of research to be funded by federal agencies. Stokes also argued that a new model of innovation is needed that considers the paths of technology innovation and increased scientific understanding as largely independent. A loose connection exists with research stimuli going in either direction. Often the coupling is use-driven basic research.

The Press report questions whether the traditional distinction between basic and applied research is useful in practice or as important in decision making as other factors, because "most federally funded research is at once both applied and basic." The university conference noted that research is divided into three tiers: short-term, product-oriented research carried out by industry, mid-term precompetitive research, also conducted primarily by industry, and long-term, fundamental research carried out mostly by universities.

The Competitiveness Council report also stressed that the complexities of modern technologies do not permit a clear distinction between basic and applied research, nor does the linear model of innovation (directly from basic research to applied research to development) reflect reality. These views were expressed in the Branscomb report, which discussed the importance of government conducting "basic technology research" as well as basic scientific research. The Council report recommended reorganizing the R&D roles of government, industry, and academia according to "short-term/low-risk" (primarily industry), "mid-term/mid-risk" (primarily industry and government), and "long-term, high-risk" (primarily universities and government) categories.

The university conference also warned that the innovation system fostered by the university/government partnership appears to be dissolving and that, without better links among academia, government, and industry, technology transfer will not be effective. The Branscomb report recommended increased governmental efforts in technology transfer at both the federal and State levels.

Changes in University Research and the Government-University Relationship

The changes discussed in the reports have affected academia significantly, including its funding by the federal government, the balance between teaching and research in universities, and the increasing need, for example, for doctoral degree holders in industry and government.

The OTA report addressed the supply of, and demand for, scientific personnel. The report concluded that the then-current estimates of shortages were overstated, but also stated that the nation's research capacity should be augmented in specific institutions of higher education, specific scientific disciplines, and under-represented groups, such as minorities and women.

The Academy report on reshaping the graduate education of scientists and engineers addressed whether academia is producing the graduates necessary to power the U.S. economy in an increasingly technologically competitive world. It concluded that, due to a number of factors, including economic, immigration, and international changes, more broadly-based graduate programs are required to prepare students, not only for careers in academia, but for positions in government and especially for the increasing number of positions for doctoral degree holders in industry. The OTA report had arrived at a similar conclusion.

The university conference noted that changes are taking place in the university/government relationship due to a number of factors, including declines in federal funding and a growing skepticism by the public of the value of university research. Those changes also are affecting the interaction between research and education. Decreases in federal funding for R&D are causing universities to divert to research funds that otherwise would have supported education. The conference argued that both the government and universities have responsibilities in rebuilding the partnership.

The Council on Competitiveness report recommended increased partnerships, not only between government and academia, but also including industry. It noted that the primary mission of universities is to educate and that, although increasingly relied on to conduct the nation's long-term research, they also are conducting increasing amounts of shorter-term research, primarily for industry. These views were echoed in the university conference report.

The Council on Competitiveness report recommended that the missions of the federal laboratories be narrowed and their overlaps be eliminated. The Press report, while not calling explicitly for downsizing the federal laboratories, emphasized the importance of funding university research.

Appendix: S&T Studies Currently Underway

A selected list of S&T projects currently underway or recently completed follows.

America Association of Engineering Societies

An historical analysis of engineering societies and the roles they have played in U.S. S&T is due about October 1997. (Contact: Gregory A. Schuckman)

Council on Competitiveness

The Global Workforce Profile project will update a March 1995 report which summarized U.S. competitiveness in human resources. The report, due in the Fall of 1997, will analyze education and adult worker training indicators and other data and assess how the U.S. is faring in response to changes in the world economy. (Contacts: Howard Samuel, Gretchen Rhines, and John Auerbach)

The Global R&D Choices project is a follow-on to the Council's report, *Endless Frontier, Limited Resources*. This project will focus on the globalization of R&D and how it impacts U.S. competitiveness. It will identify those nations emerging as global R&D competitors, what drives the international diffusion of U.S. corporate R&D, and what the United States should do to encourage investment in innovation at home. This project will lead to three reports:

Sector Roadmaps (due Fall of 1997) will study how companies form innovation strategies and which governmental policies encourage and discourage innovation. Five industrial sectors will be studied. *Innovation Index* (due Winter of 1997)will serve as a new benchmarking effort to compare vital elements of national innovation systems in Europe, Asia, and Latin America. *National Innovation Strategy* (due Spring of 1998) will integrate the findings and recommendations of the project into a national strategy to encourage investment in innovation and make specific recommendations to Congress and the Executive Branch on how to create an environment that attracts industry investment. (Contacts: Debra Van Opstal and Chad Evans)

Georgia Tech University

A three-year study of DOE's Basic Energy Sciences program support of scholarship research and the resulting commercial impacts. (Contact: David Roessner)

National Academy of Sciences, Committee on Science, Engineering, and Public Policy

As a follow-on to the 1993 report, *Science, Technology, and the Federal Government: National Goals for a New Era*, COSEPUP is engaged in a series of "bench marking" exercises to assess chosen areas of U.S. research (mathematics, materials science and engineering, and immunology) in comparison to other nations. (Contact: Deborah Stine)

As a follow-on to the 1995 report, *Allocating Federal Funds for Science and Technology*, COSEPUP is currently considering using a Federal Science and Technology (FS&T) budget analysis to determine the impact of changes in the federal budget on science and technology. (Contact: Deborah Stine)

As a follow-on to the 1993 report, *Science, Technology, and the Federal Government: National Goals for a New Era*, COSEPUP is analyzing cases in which the United States is capitalizing on its leadership in some areas of research and applications, that is, where it is the leader, or among the leaders, in various fields. Specific areas, including catalysis and piezoelectric ceramics, are being studied for cross-cutting issues and general conclusions. (Contact: Tom Arrison)

Government-University-Industry Research Roundtable

See National Science Board, below.

National Science Board and the Government-University-Industry Research Roundtable (GUIRR) of the National Academy of Sciences

As a follow-on to the 1993 Phase I of the "Stresses on Research and Education at Colleges and Universities" project, Phase II will expand the number of institutions involved to foster discussion and change on campus, encourage a national dialogue, and revise or recast the compact between universities and federal government. This will be an input to the review of the university-government partnership by the National Science and Technology Council, see below. (Contacts: Allison Rosenberg (GUIRR) and Marta Cehelsky (NSB))

National Science Board

A public meeting in Houston in October 1997 will include discussions focusing on graduate education in the United States. Subsequently, the Board will conduct an assessment of the subject that will be an input to a Presidential Review Directive on the government-university partnership. (Contact: Marta Cehelsky)

As a companion piece for the upcoming 1998 *Science & Engineering Indicators* report, the Task Force on Industry Reliance on Publicly-Funded Research is preparing a report due in November 1997. (Contact: James McCollough)

The Task Force on Strategic Science and Engineering Policy Issues is preparing a working paper on *Government Funding of Scientific Research.* (Contact: Marta Cehelsky)

National Science and Technology Council

In response to a Presidential Review Directive (9/26/96), the NSTC has formed a task force to review the university-government partnership and determine the major stresses in the areas of research, education, and administrative regulations, and what the federal government's role should be. (Contact: Sybil Francis)

The NSTC has established an interagency working group on federal laboratories to address recommendations which resulted from the report, *Status of Federal Laboratory Reforms*, issued in March 1997, that focused on DOD, DOE, and NASA laboratories. The group will look at extending the reforms to other federal laboratories and review barriers to laboratory reform, share lessons learned across government, and develop and implement an action plan to continue the reform process. (Contact: Beverly Hartline)

RAND Corporation

A recently completed study of the future of higher education in the United States, *Breaking the Social Contract: The Fiscal Crises in Higher Education* (June 1997), includes a chapter on the distribution of federal R&D support among universities. (Contact: Stephen Carroll)

SRI International

On-going studies of the role of: NSF in 12 major industry innovations (for NSF), how 13 of NSF's Energy Research Centers are confronting the situation of "graduating" from NSF sponsorship after the 12-year sponsorship period (for NSF), and the cultural impacts of Energy Research Centers on universities; and a literature review of university-industry and federal laboratory-industry cooperative research projects. (Contact: David Roessner)