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Some Perspectives on the Changing Role of the U.S. Government in Science and Technology

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ABSTRACT

The report analyzes a number of factors bearing on the government's role in science and technology (S&T): the character of research and development (R&D) supported by the government (basic and applied research and development); the federal R&D missions involved (such as defense, energy, space, and the support of much of the nation's university basic research); whether the government funds R&D in its own laboratories or in those of industry or academia; and the government's R&D budget and its management of, and planning for, S&T. The report also summarizes six studies, by governmental and nongovernmental entities and individuals, that deal with the government's changing role in S&T from their perspectives. There are no plans at this time to update this report.

Some Perspectives on the Changing Role of the U.S. Government in Science and Technology

Summary

The Congressional Research Service was requested by the House Committee on Science to provide a report on the role of the U.S. government in science and technology as an input to the Committee's national science policy study. This report analyzes a number of factors bearing on the government's role in science and technology that may be taken into consideration in the formulation of federal science policy.

The role of the U.S. government in science and technology varies according to a number of factors: the character of research and development supported by the government (basic research, applied research, or development); the federal research and development missions involved (such as defense, energy, space, and support of much of the nation's university basic research); whether the government conducts research and development in its own laboratories or supports other performers of research and development (such as industry, academia, the states, and foreign entities); and the federal research and development budget and the government's management of, and planning for, science and technology. Government's role in the nation's science and technology increased dramatically during and immediately after World War II. Since then, further changes have occurred, perhaps the most important being the continuing decrease in the percentage of federal versus nonfederal funding of research and development since the late 1970s. Other changes, some caused by those federal funding changes, involve the government's relative support of basic and applied research and development, its defense-related versus civilian R&D missions, and its relationships with the nation's other funders and performers of R&D — mainly industry and academia.

This report also summarizes six studies, by governmental and nongovernmental entities and individuals, that deal with the government's changing role in science and technology from their perspectives. Those studies were selected by the Committee as representing a cross-section of many such reports produced since 1993. The first report summarized is the concluding report of the Carnegie Commission on Science, Technology, and Government, which resulted in over 300 recommendations covering the full range of issues in science and technology. The second report was by the Executive Office of the President. It covers about the same range of issues as covered in the Carnegie Commission report but from the perspective of the Administration. The third report, sponsored by a bipartisan federal advisory commission, deals in depth with technology innovation policy. The fourth report is the product of a university conference concerned with revitalizing the "government-university partnership," especially in regard to federal support of academic research and the training of scientific and technical personnel. The fifth is a Commerce Department report detailing the recent evolution of public-private cooperation ("partnering") in the nation's R&D establishment. The sixth report is an analysis by an economist of the "price" that the United States might have to pay for long-term downsizing of the federal investment in research and development.

Acknowledgments

William C. Boesman is the coordinator of this report and author of the section on the role of the U.S. government in science and technology and of one of the individual report summaries. Other CRS specialists who prepared report summaries are Michael E. Davey, Genevieve J. Knezo, Glenn J. McLoughlin, Richard E. Rowberg, and Wendy H. Schacht of the Science, Technology, and Medicine Division.

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Some Perspectives on the Changing Role of the U.S. Government in Science and Technology

Introduction

Congress deals with many aspects of science and technology (S&T) on a continuing basis: in its legislative oversight activities, in the development of S&T policies, in responding to the Administration's research and development (R&D) plans and budgets, and as a component of broader policy issues. In the 105th Congress, Members and committees are looking at the future of U.S. science and technology and S&T policy.[1] An important aspect of this examination is the role of the U.S. government in S&T as the nation enters the 21th century. The Congressional Research Service was requested to provide a report on this subject as an input to the bipartisan national science policy study, headed by Representative Vernon J. Ehlers, of the House Committee on Science.

There are several ways to examine the role of the U.S. government in science and technology. One is to explore that role in terms of the *character* of the research and development performed — for example, whether it is basic research, applied research, or development. Another way is by the *federal missions* supported, such as defense-related R&D; health, energy, space, or other civilian R&D; or the government's support of mathematical and science education and university research. Also, the role of the government in S&T is being discussed increasingly in terms of actual or possible federal *cooperation with other performers* of R&D, including the private sector, academia, the states, and international entities. Lastly, the government's role in science and technology is significantly affected by the level of its *R&D budget* and the effectiveness of its *R&D management and planning*.

At the heart of the debate about U.S. science and technology policy are the difficult issues of the federal role in maintaining the health of the nation's science and technology and the proper balance among the performers of S&T. For example, what is the "best" level and mix of federal support of research in universities versus in federal laboratories; or what is the government's role versus that of the private sector in the promotion of nation's technological development?

In addressing these questions, Congress and the executive branch receive a steady stream of reports, from government agencies, nongovernmental organizations, academia, and others, on many aspects of S&T policy. This report summarizes six recent studies that address the role of the U.S. government in science and technology and analyzes their findings in terms of the factors mentioned above (character of

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[1] See, for example, Vernon J. Ehlers, "The Future of U.S. Science Policy," *Science* 279 (16 January 1998): 302.

R&D, federal missions, other R&D performers, and federal R&D budgets and management).[2] Those reports represent a cross-section of studies prepared since 1991. They were selected by the Committee after consultation with analysts in S&T policy in the Congressional Research Service. Their selection was based upon one or more of the following criteria: The reports are recognized as influential, express a range of views, were written by leaders in the field, focus on one or more of the subjects covered, and/or represent views of current policymakers. The six reports may not represent all policy perspectives. Following the report-summary section is an appendix of acronyms of some federal departments and agencies referred to in the report.

The Changing Role of the U.S. Government in Science and Technology

This section addresses the changing role of the U.S. government in science and technology in terms of the character of the research and development performed, federal missions supported, federal support of other performers of R&D, and federal R&D budget, management, and planning activities. It analyzes these factors in reference to the six reports summarized in the next section.

Character of Research and Development

One way the federal government collects information on research and development is according to whether it can be classified as basic research, applied research, or development.[3] The government historically has supported much of the nation's basic research, mainly expensive, long-term, and/or risky research, that could not or probably would not be supported by the industrial sector or academia. Examples are research on nuclear weapons and in high-energy and nuclear physics conducted by the Department of Energy, physical science and engineering research supported by the National Science Foundation, and biomedical research conducted or supported by the National Institutes of Health. Applied research projects in many scientific and engineering mission-related areas are supported by federal mission agencies, such as the Departments of Defense and Energy, NASA, NIH, and NSF. In terms of development, two agencies account for about 88% of the development projects funded by the government: DOD (75%) and NASA (13%).[4]

The role of the federal government in relation to the character of R&D is at issue in at least two ways. First, there is a perennial divergence of opinion among science

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[2] CRS recently analyzed U.S. science and technology policy efforts since World War II and summarized ten reports that dealt with a broad range of current S&T policy issues. See Congressional Research Service, *Analysis of Ten Selected Science and Technology Policy Studies*, by William C. Boesman, Report 97-836, 24 October 1997, 51 pp.

[3] See, for example, the extensive R&D data series published by the National Science Foundation, such as those cited in footnotes 4 and 17.

[4] FY1997 data from National Science Foundation, *Federal Funds for Research and Development: Fiscal Years 1995, 1996, and 1997*, NSF 97-327 (1997), 145-147.

policymakers as to whether the government should increase or decrease its funding support of basic research, applied research, and/or development — particulary civilian applied research and development — vis-a-vis the private sector. (Whether the government should increase or decrease support for R&D is closely tied to the specific type of R&D being considered for support, rarely to the broad categories of basic research, applied research, or development in totality.) This seems to be particularly contentious today in discussions of federal technology policy, as addressed in several of the reports summarized in the next section. Federal R&D budget issues are discussed later in this section.

Second, the terms and models themselves — for example, basic research, applied research, and development, and the so-called "linear model" of research — may not adequately capture important aspects of the spectrum of scientific and engineering endeavors — from basic or fundamental research through technological development, innovation, and commercialization. A number of different terms and approaches have been suggested in the recent scientific literature, including in the reports summarized in this analysis.

- The one-dimensional, or "linear," model of research, proceeding from curiosity-driven basic research through use-driven applied research and innovation, the so-called "Bush model,"[5] is suspect and considered by many to be inadequate today. The importance of basic research driven by a desire to solve a practical problem, and the complex relationship between basic research and technological development, should be recognized.[6]

- Some policy studies have recommended that the government abandon its use of the terms "basic research" and "applied research" and instead concentrate, not just on basic research, but on long-term, high-risk, need-based "basic technology research."[7]

- Likewise, instead of characterizing R&D as basic and applied research and development, it may be more useful to organize R&D by its time horizon and level of risk: short-term/low-risk (primarily conducted by industry, and also by not-for-profits); mid-term/mid-risk (primarily industry and government, also academia); and long-term/high-risk (primarily academia and government, also government and industry).[8]

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[5] Vannevar Bush, *Science — The Endless Frontier* (1945, reprinted by the National Science Foundation, May 1980), 192 pp.

[6] Donald E. Stokes, *Pasteur's Quadrant: Basic Science and Technological Innovation*, (Washington: Brookings Institution Press, 1997), 175 pp., summarized in CRS Report 97-836: 40-43.

[7] Lewis M. Branscomb and James H. Keller, eds., *Investing In Innovation: Creating a Research and Innovation Policy That Works* (Cambridge: MIT Press, 1998), 516 pp. See the Summary section, below.

[8] Council on Competitiveness, *Endless Frontier, Limited Resources: U.S. R&D Policy for Competitiveness* (Washington: Council on Competitiveness, 1996), 145 pp., summarized in CRS Report 97-836: 29-33.

- Using still different terminology, a recent science policy conference noted that the important "mid-tier" of the research hierarchy, precompetitive research conducted by industry, has all but disappeared.[9] This indicates the importance, for policy analysis and policymaking, of adequately defining the character of R&D.

- A recent proposal to modify R&D terminology used for federal budget purposes noted that "most federally funded research is at once both applied and basic." It recommended that a Federal Science and Technology (FST) budget include basic and applied research and fundamental technology development, but exclude "initial production, maintenance, and upgrading of large-scale weapons and space systems at [DOD, DOE, and NASA]."[10]

To understand the role of the federal government in S&T requires an examination of the terms and models used to characterize research and development. Recent reports suggest that there is a growing acknowledgment among those involved in science policy analysis and policymaking that a clarification of terms used to characterize R&D and innovation would not be just an exercise in semantics, but could have important substantive policy ramifications. For example, there may be an important "mid-tier" of research — pre-competitive research conducted by industry — that is disappearing. When such research is characterized as part of another category of R&D, however, it may not be apparent that there is a problem. Likewise, there are questions today about the validity of the "linear model" of research and innovation, which may bear on the government's role in supporting some research and development.

Federal R&D Missions

The role of the government in research and development varies according to the federal mission involved. Since World War II, for example, the government has played a dominant role in defense-related R&D because it is carried out for national security purposes and because the government has been the sole or principal customer of the technologies and products developed. Much space R&D also is a federal mission where the government has been the sole or principal customer. This situation may be changing, in part, as federal funding for defense-related R&D continues to decline significantly in real terms and as the military increasingly relies on purchasing or adapting dual-use technologies generated in the industrial sector for commercial ends, rather than for defense R&D programs. A recent study recommended that, in light of these two trends, the nation move toward a single, national technology base, rather than having separate defense-oriented and

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[9] Gary D. Krenz, ed., *Proceedings of the 1996 Jerome B. Weisner Symposium: The Future of the Government/University Partnership* (Ann Arbor: University of Michigan, Feb. 26, 1996), 251 pp. See the Summary section, below.

[10] National Academy of Sciences et al., *Allocating Federal Funds for Science and Technology* (Washington: National Academy Press, 1995): 52, 77, summarized in *CRS Report 97-836*: 22-25.

commercial technology bases.[11] If that were to occur, the government's role in defense R&D, in many cases, may shift from that of a "dominant developer" to that of a "preferred customer." However, even though DOD may be using more commercial off-the-shelf technology than previously, the government still is the primary funder of defense-related R&D.

In civilian R&D, the government has been the dominant funder of many areas of basic research, including physical science supported by the National Science Foundation and the Department of Energy and biomedical research supported by the National Institutes of Health. Support of much basic research is a federal mission because it is considered by most policymakers to be public good important to the nation, but it could not or would not be performed without federal support. It generally has had broad support in Congress, even when other components of civilian research have had less support.

More controversial is the federal role in support of civilian applied research and development, particularly in those areas of R&D and innovation where industry has natural commercial interests. This issue has been particularly prominent in the interactions between the Clinton Administration and the 104th and 105th Congresses.[12] Several of the reports summarized below, for example, discuss the pros and cons of the Advanced Technology Program (ATP) of the Department of Commerce and an increased federal role in technology support programs.

Another area in which the government's role may be controversial is in R&D policy linking the environment, energy, and the economy (the so-called "E^3" policy area). A recent report[13] characterized federal environmental R&D as impressive, but diffuse and uncoordinated. In addition, the government's role in promoting the environment may affect national energy production and use and, consequently, national economies. Congress must face these issues, many of them R&D-related, in its consideration of the economic and energy issues inherent in the Kyoto Protocol on global climate change.[14]

The federal government also historically has had a strong role to play in university research and the education of scientists and engineers at the undergraduate and graduate levels. Increasingly, also, it has assumed a role in the mathematics and

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[11] Carnegie Commission on Science, Technology, and Government, *Science, Technology, and Government for a Changing World: The Concluding Report* (New York: Carnegie Commission on Science, Technology, and Government, 1993), 94 pp. See the Summary section, below.

[12] Executive Office of the President, Office of Science and Technology Policy, *Science and Technology Shaping the Twenty-First Century* (April 1997), 141 p.; and Branscomb and Keller, *Investing In Innovation: Creating a Research and Innovation Policy That Works*. See the Summary section, below.

[13] Carnegie Commission, *Science, Technology, and Government for a Changing World*, see the Summary section, below.

[14] See, for example, Congressional Research Service. *Global Climate Change Treaty: Summary of the Kyoto Protocol*, by Susan R. Fletcher, Report 98-2, 22 December 1997, 5 pp.

science education at the kindergarten through high school (K-12) levels. The government's role in education involves its relationships with academia and the states, as discussed below.

Partnerships With Other R&D Performers

During and following World War II, the federal government forged strong R&D ties with industry and academia. Until 1977, the government *funded* more than 50% of the nation's research and development, although industry was the major *performer*[15] of the nation's applied research and development. By 1997, the government's funding of the nation's total R&D had decreased to about 30%, while industry's funding had increased to about 65%. In terms of *performance* of the nation's total R&D in 1996, industry performed almost 73%. In 1996, academia performed about 50% of the nation's basic research, or 60% if research performed by FFRDCs[16] operated by universities and colleges is taken into account.[17] Although the government still funds the majority of academic R&D (about 60% in 1995), this has decreased from about 73% in the 30 years since 1965.[18] The federal government is a less dominant partner with industry and academia than it has been in the past.

An aspect of the changing role of the federal government in science and technology involves what, if anything, should be done with the federal laboratory complex. The federal government has the nation's largest laboratory complex and is the nation's largest employer of technical personnel. Many of these laboratories, scientists, and engineers are considered to be world class. Questions have arisen over the last several years, however, as to the whether all of these laboratories are fulfilling important or productive federal missions, whether some of them are redundant, whether some of them should be closed or sold, and how they relate to the R&D capabilities of the private sector. In the 104th and 105th Congresses, for example, legislation was introduced to eliminate DOE and evaluate the future of its laboratories.[19] Although it is likely that the government will maintain its own laboratory system in many R&D areas, such as in national defense and in certain areas of basic research, real decreases in federal R&D budgets in future years could

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[15] The major funders and performers of R&D generally are classified as the federal government, industry, universities and colleges, and nonprofit institutions.

[16] Federally Funded Research and Development Centers are owned by the federal government, but are managed and staffed by nonfederal personnel under contract with the government.

[17] 1997 data are from Steven Payson, "R&D Exceeds Expectations Again, Growing Faster than the U.S. Economy during the Last Three Years," *Data Brief*, NSF 97-328 (5 November 1997): 2; 1996 data are from National Science Foundation, *National Patterns of R&D Resources: 1996,* NSF 96-333 (1996): 77, 80, 86.

[18] NSF, *National Patterns: 75-76.*

[19] Congressional Research Service, *DOE Laboratory Restructuring Legislation in the 104th Congress*, by William C. Boesman, Report 97-558 13 May 1997, 13 pp.; and Congressional Research Service, *Restructuring DOE and Its Laboratories: Issues in the 105th Congress*, by William C. Boesman, CRS Issue Brief 97012, 2 April 1998.

result in fewer federal laboratories and in greater federal reliance on private sector laboratories than in the past.

The government's traditional role vis-a-vis industry is that of being the primary customer of federally funded R&D performed in industrial laboratories. This role, of customer, may be expanding as government relies more on dual-use technologies initiated in the private sector. Also, federal "partnering" with industrial laboratories is increasing, although it represents only a small proportion of total U.S. R&D funding. In these cases, government is a"partner with the private sector in developing and deploying new commercial technologies that fulfill [federal] mission objectives and enhance U.S. industry's market strength."[20]

Another partnership relationship is that between the government and academia, particularly the government's role in the funding and managing of research in universities and colleges and supporting the education of scientists and engineers. There is evidence that the strong, 50-year-old federal-academic relationship is showing signs of strain and needs to be revitalized.[21] This is of major concern to policymakers in Congress addressing the future of federal science policy.

Another aspect of the government's role in "public science" (that is, science conducted in federal laboratories, universities and colleges, and other public institutions) is its importance to industry. A recent study, supported by the National Science Foundation, found "that public science plays an essential role in supporting U.S. industry, across all the science-linked areas of industry, amongst companies large and small, and is a fundamental pillar of the advance of U.S. technology."[22]

The states were identified in a recent study as ready to become "full partners with the federal government in meeting [America's contemporary] challenges."[23] While this would enhance the role of the states in contributing to national development through R&D, it would also enhance the role of the federal government as the senior partner in the relationship because of the government's broader experience and R&D capabilities. A specific aspect of the need for the federal government's leadership in this partnership was identified in the same study — federal leadership will be required over the next two or more decades if the nation's pre-college educational system, basically a state responsibility, is to be improved significantly.

The government's role in international S&T partnerships also seems to be changing, from a traditional tendency toward independence in conducting national

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[20] Department of Commerce, *Effective Partnering: A Report to Congress on Federal Technology Partnerships* (Washington: GPO, April 1996): 20. See the Summary chapter, below.

[21] Krenz, *The Future of the Government/University Partnership*.

[22] Francis Narin et al. "The Increasing Linkage Between U.S. Technology and Public Science," *Research Policy* 26, October 1997: 330.

[23] Carnegie Commission, *Science, Technology, and Government for a Changing World:* 25.

R&D projects to recognition of the importance of international cooperation. [The DOE's Superconducting Super Collider (SSC) project, for example, was designed and conducted as a U.S. project without foreign cooperation, except for foreign assistance in developing some components. After that project was terminated by the Congress in 1993 for, among other things, funding problems, DOE entered into negotiations with CERN (the European Laboratory for Particle Physics) for U.S. participation in the Large Hadron Collider (LHC) project. The United States currently is committed to about $450 million for this high-energy physics project.] The federal government is involved in many other international R&D agreements and projects and, according to some observers, may require stronger and more centralized federal S&T leadership and coordination than currently exists, including in the Department of State.[24] As noted below in the Summary section, however, the Department of State recently eliminated an important S&T position and reorganized it S&T capabilities.

R&D Budget, Management, and Planning

The government's FY1999 budget shows real increases in total R&D funding and real increases for nondefense R&D funding through FY2003. The President, however, has proposed that most increases in civilian R&D be paid from increases in the Research Fund For America (RFFA), 90% of which are dependent on money that would be obtained from the tobacco industry settlement, congressional approval of which is uncertain. If it does not approve the tobacco settlement, Congress may not fund the proposed R&D increases for some civilian discretionary programs, including research and development.[25] That would be particularly likely if the Congress enacted the Intermodal Surface Transportation Efficiency Act (ISTEA),[26] with its six-year funding at $23-30 billion annually. Moreover, the Senate budget resolution[27] recommends, among other things, a 1% reduction for FY1999 from the FY1998 level for the budget functions that include civilian DOE, NSF, and most NASA R&D. The National Research Investment Act of 1998,[28] on the other hand, would increase R&D funding in 12 selected agencies from $34 billion in FY 1998 to $68 billion in FY 2008. Given these conflicting actions, near-term federal R&D funding is uncertain.

The composition of the federal R&D budget significantly affects the overall character of the nation's R&D (the relative support of basic research, applied research, and development — to use the usual terms); the government's R&D missions (the relative support of defense versus civilian R&D programs); and cooperation with, and support of, the government's "partners" (industry, academia, states, and foreign entities). The importance of the federal R&D budget may be

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[24] Ibid. 29.

[25] Congressional Research Service, *Research and Development Funding: Fiscal Year 1999*, coordinated by Michael E. Davey, IB98011, 24 February 1998.

[26] S. 1173, H.R. 2400 of the 105th Congress.

[27] S. Con. Res. 86 of the 105th Congress.

[28] S. 1305 of the 105th Congress.

magnified because, in many ways, it is the de facto federal science policy.[29] But whatever the composition of the federal R&D budget at any given time, its absolute level in comparison with historical trends also is important in terms of the nation's economic and cultural development. While there might be benefits from a protracted downsizing of the federal investment in the nation's science establishment, such as contributing to reduction of the national debt and the elimination of waste and redundancy in federal laboratories and other laboratories supported by the government, there also might be long-term social and cultural "costs". If the federal investment in R&D is smaller in the future, it is possible that the nation's economic return on that investment also would be smaller than it otherwise would have been. In the words of one of the reports summarized below, this would lead to

> a picture of diminished excellence, with increasingly evident traces of mediocrity. . . . Moreover, with the depleted science infrastructure that exists in the downsized future, it will be difficult to catch up with what the nation could have achieved under an alternative scenario of healthy scientific growth . . . [30]

An elaborate federal structure has evolved since World War II to manage the government's R&D and formulate and coordinate federal S&T policy. Some recent reports have made recommendations as to how to improve that structure, including long-term planning capabilities, to ensure that the health of the nation's science and technology is maintained into the 21st century. These recommendations include institutionalizing long-term S&T goal-setting as part of the policy-making and budget-setting processes in Congress and the executive branch.

A Balanced Role

The six reports summarized in the next section[31] were selected as a small cross section of the available literature representing the general range of opinions of policy analysts and policymakers on the government's role in S&T. Each report addressed, to a greater or lesser extent, the various factors (character of research and development, federal R&D missions, R&D partners, and federal S&T management) discussed above. Although they expressed various perspectives (those of an independent commission, the Executive Office of the President, a bipartisan study group sponsored by a federal advisory commission, a university conference, a federal department, and an economist), they are serious attempts to address the various aspects and ramifications of the government's role in science and technology.

The Carnegie Commission, over six years, made over 300 recommendations in 15 areas of S&T policy. These are summarized in *Science, Technology, and Government for a Changing World: The Concluding Report*. In regard to the role of the federal government in science and technology, it made many recommendations

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[29] Ehlers, "The Future of U.S. Science Policy." In this article, Rep. George E. Brown, Jr. was quoted as saying: "We don't have a science policy, we have a budget policy."

[30] Kenneth M. Brown, *Downsizing Science: Will the United States Pay a Price?* (Washington: The AEI Press, 1998): 126-128. See the Summary section, below.

[31] Full citations are given in the report summaries in the next section.

for improving federal R&D policy direction and for federal cooperation with industry, the states, and foreign nations and entities. It recommended strengthening federal technology policy; formulating policies linking the environment, energy, and the economy; and establishing new federal mechanisms for institutionalizing long-term planning in support of the nation's science and technology.

The 1997 White House report on *Science and Technology Shaping the Twenty-First Century* dealt with science, technology, national security, the environment, health, and human resources, practically the entire spectrum of issues covered in the Carnegie Commission report, but from the perspective of the executive branch. The report discussed the direct role of the federal government in its R&D agencies, its laboratory system, and its support of university research. It also noted that the government has an important, although indirect role, in catalyzing non-federal S&T institutions to function effectively.

Investing In Innovation: Creating a Research and Innovation Policy That Works, edited by Branscomb and Keller, is a report of a study group sponsored by a bipartisan federal advisory commission. It concentrated on one of the major issue areas addressed in the first two reports discussed above. The issues involved the policy debate between the Republican-controlled Congress and the Clinton Administration regarding the appropriate federal role in fostering technological innovation. The report recommended that increased attention be given to an important "gray area" of research — basic technology research — that often has been overlooked and in which both the government and the private sector have a role to play. The report called for a new comprehensive and sophisticated technology policy that is adaptable to changing competitive conditions.

The university conference on *The Future of the Government/University Partnership* addressed a widespread concern in academia — the future of research support by the government and the need for a new science policy with specific regard to academic support by the government. Most participants agreed that the government should support long-term fundamental research and many noted that the government might have a role in supporting "mid-term," precompetitive research. Such research provides a link between the knowledge base and products that has almost disappeared because global economic pressure has forced U.S. industry to concentrate on new product development. It also was generally agreed that a critical contribution of academia to the partnership is its training of scientific and technical personnel and that the support of education through the research process is one of the government's most important roles.

The Department of Commerce report, *Effective Partnering: A Report to Congress on Federal Technology Partnerships,* addressed the importance of federal-industry "partnering" (an aspect of technology policy) in U.S. science and technology. This was one of the concerns also addressed in the Carnegie Commission, White House, and Branscomb reports. The Commerce report discussed a significant change currently occurring in the federal-industry relationship — from government as the primary customer of federally funded R&D to government as a partner with industry in developing new commercial technologies that meet both federal mission objectives and contribute to the nation's commercial strength. The report noted that the economic well-being of the industrial sector is a major concern of the government, just as the university conference noted that the well-being of academia is a concern of the government.

The Brown book, *Downsizing Science: Will the United States Pay a Price?* asked whether the United States would pay a cultural and economic price for downsizing its federal investment in the nation's science establishment and answered in the affirmative. The report discussed how an appropriate federal role in support of academic research, federal laboratories, and industrial R&D could prevent the nation from having to pay such a price. It offered criteria to evaluate legitimate governmental funding for each of these three R&D sectors. Some of the conclusions of the book — for example, in regard to the Department of Commerce's Advanced Technology Program — conflict with those of other reports discussed above.

Many other aspects of the government's role in science and technology were addressed in these reports, which are summarized in the following section.

Summaries of Selected Reports on the Government's Role in S&T

Six S&T reports are summarized in this section.[32] Each three- to five-page summary contains a brief background discussion about the report; a discussion of key aspects of the report regarding the role of the U.S. government in science and technology; and the findings and/or conclusions of the report.

Science, Technology, and Government for a Changing World[33]

Background of the Report. In April 1988, the philanthropic Carnegie Corporation of New York established the Commission on Science, Technology, and Government to address the "profound difficulty for governments of meeting the challenge of accelerating scientific and technological developments" (p. 4). The commission was composed of over 200 S&T experts and distinguished scientists, industrialists, lawyers, politicians, and former governmental officials, including

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[32] For ease of reference, abbreviated citations are given here. A full citation is given in each report summary.

Carnegie Commission , *Science, Technology, and Government for a Changing World: The Concluding Report*.

OSTP, *Science and Technology Shaping the Twenty-First Century*.

Branscomb and Keller, *Investing In Innovation: Creating a Research and Innovation Policy That Works*.

Krenz, *The Future of the Government/University Partnership*.

Department of Commerce, *Effective Partnering: A Report to Congress on Federal Technology Partnerships*.

Brown, *Downsizing Science: Will the United States Pay a Price?*

[33] Carnegie Commission on Science, Technology, and Government, *Science, Technology, and Government for a Changing World: The Concluding Report* (New York: Carnegie Commission on Science, Technology, and Government, April 1993), 94 pp. Unless otherwise noted, all quotes in this section are from that source.

former Presidents Ford and Carter. From 1988 through 1993, it published 19 reports, including this 1993 summary, produced about 12 other background and related studies, and sponsored 6 books and studies that were published elsewhere. From 1993 through 1996, commission staff performed follow-up work, and task force chairman discussed many of the report's recommendations with government officials. According to the commission, many changes in federal S&T policy have been made as a result of those recommendations. In 1996, the commission met for the last time and approved a final report on S&T and the next (Clinton) administration.

The commission made over 300 recommendations on S&T policy in 15 areas of focus: the President, 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, precollege 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. In 14 of these areas, the commission published one or more formal reports. No formal report was published on recruiting and retaining federal scientists and engineers. The role of the federal government in S&T was addressed throughout the reports.

Key Aspects Regarding the Role of the U.S. Government in S&T. The context of the Carnegie Commission reports is that the federal government has a continuing, essential role to play in U.S. science and technology. The summary report, for example, seems to assume that the U.S. government will or should continue to maintain its funding support of many areas of basic research (for example, high energy physics and other areas of fundamental science that otherwise would not be supported); applied research and development in furtherance of the government's missions (for example, defense, health, energy, space and aeronautics, and agriculture); and science and engineering education and scientific research in the nation's universities and colleges.

The report also recommends improvements in the government's technical (scientific, engineering, and S&T policy) leadership. A major theme of the summary report, reflecting that of the individual reports, is that closer cooperation is necessary between the U.S. government and industry, the states, nongovernmental organizations (NGOs), and foreign nations. In addition, the report discusses the commission's proposal for federal policies linking the environment, energy, and the economy. These aspects are discussed in the next section.

Findings and/or Conclusions. The commission's report dealt with improvements in federal R&D policy direction; federal R&D cooperation with industry and the states; federal R&D cooperation across agencies and with foreign nations and entities; federal policy linking the environment, energy, and the economy; and long-term S&T planning.

Improvements in Federal R&D Policy Direction.[34] The report recommended improvements in many aspects of federal R&D policy direction, oversight, and planning. It recommended that Congress improve congressional access to expert advice and internal organization to better deal with S&T issues. In the Executive Office of the President, the S&T policy structure should be enhanced, which, the report stated, already had occurred to some extent because some of the commission's recommendations had been implemented. Examples included the elevation of the President's science advisor to cabinet status and the reestablishment of the President's Science Advisory Committee (PSAC) in the Bush Administration, and the formulation of the Clinton Administration technology policy, which "is very much in tune with the recommendations of the commission."[35] The report recommended assistance to the judiciary to improve its management and adjudication of the increasing number of cases involving complex science and technology issues. The independent regulatory agencies are sometimes referred to as the fourth branch of government. The report recommended that the Executive Office of the President, in cooperation with Congress and the judiciary, take the lead in providing broad S&T policy guidance and in setting and implementing coherent regulatory priorities for these agencies.

To improve the government's technical capabilities at the highest level, specifically those of the approximately 80 top presidential S&T appointments, the commission recommended improvements in recruitment and reductions of barriers to ensure that the most highly qualified scientists and engineers are able to fill the positions. The federal government is the largest employer of technical personnel in the nation. The report recommended that Congress and agencies in the Executive Office of the President develop improved personnel policies (including salaries comparable to the private sector) for the approximately 200,000 scientists and engineers in the federal government, who account for about 10% of all federal employees.

Cooperation with Industry.[36] With the dramatic decrease in U.S. defense R&D spending in the post-Cold-War era, and the military's increasing reliance on technologies generated in the commercial sector, the commission recommended that steps be taken to integrate the nation's defense and civilian technology bases into a single dual-use (commercial and military) technology base. To shape and implement federal policy related to economic performance and the national technology base under these new conditions, technology policy in the Executive Office of the President should be enhanced. The report recommended that the Department of Commerce play a more active role in forging strong partnerships with business, labor, and universities. That would involve an expanded role for the Advanced Technology Program (ATP) of the National Institute of Standards and Technology (NIST). Both the "National Security" and "Economic Performance" chapters of the report

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[34] See the chapters "The White House," "Congress," "Judicial Decision Making," "Regulation," and "Government's Technical Leadership."

[35] 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: 3.

[36] See the chapters " National Security" and "Economic Performance."

recommended broadening the Defense Advanced Research Projects Agency (DARPA) from its exclusive emphasis on defense, as a step toward creating a broader national technology base.[37]

Cooperation with States.[38] The report recommended that, with the end of the Cold War, the states should become "full partners with the federal government in meeting [America's great contemporary] challenges" (p. 25). That would include states being represented on federal S&T advisory and decision-making organizations, including those defining missions for federal laboratories. The report also recommended that each state establish a science advisor to its governor and an S&T advisory board for its legislature and aim toward establishing a national organization to assist states in S&T matters. Already in existence in most states are technology programs, the majority of which promote business-driven partnerships between industry and academia.

The chapter on "Education" noted that, although kindergarten through high school (K-12) education always has been mainly a state and local responsibility, the system has proven to be inadequate for improving science and mathematics education nationally. The commission also found that the federal effort, including the activities of the Department of Education and the National Science Foundation, was "divided and incoherent" (p. 50). The report stated that presidential leadership and bipartisan commitment will be necessary over the next two or more decades if the nation's precollege educational system is to be improved significantly.

Cooperation Across Agencies and With Foreign Nations and Entities.[39] The report stated that the "international relations of the United States have suffered from the absence of a long-term, balanced strategy for issues at the intersection of science and technology with foreign affairs" (p. 29). It recommended that international S&T responsibilities be clarified across federal agencies and particularly in the Department of State; for example, that a position of Science and Technology Counselor to the Secretary of State be established and that the number of S&T officers in U.S. embassies be increased.[40] "Overall, there are three aims for the mid-1990s: to define afresh the U.S. international goals in and for S&T; to bring the increasingly important international programs into the mainstream *throughout* the S&T agencies of the government; and to orchestrate use of the nation's full technical assets, especially from the private sector, in order to fulfill the goals of American foreign policy" (p. 31).

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

[38] See the chapters on "States" and "Education."

[39] See the chapters "International Affairs," "Global Development," and "International Science Advice."

[40] This situation may have become worse since the commission's report. The Department of State has eliminated its highest-ranking S&T position, the deputy assistant secretary for science, technology, and health, and has reorganized the Bureau of Oceans and International Environmental and Scientific Affairs (OES). See Ken Jacobson, "State Drops Top S&T Post, Puts Chips on Environment," *New Technology Week*, 11, 28 July 1997: 1, 6-7.

Science and technology have an important role to play in global development, but their effective application requires presidential leadership. The report recommended the establishment of a National Action Roundtable for International Development to mobilize, for specific challenges, the government, the private sector, and nonprofit institutions. It also recommended that the Agency for International Development increase its access to U.S. science and technology and improve its operations.

Federal Policy Linking the Environment, Energy, and the Economy (E^3).[41] In addition to the general recommendations to improve federal R&D policy direction, noted above, the commission also dealt specifically with the federal policy role in linking the environment, energy, and the economy. The report noted that the federal government's environmental R&D system is impressive in many ways, but it is diffuse and uncoordinated. More far-reaching, however, is the commission's view of the importance to the nation of linking environmental quality, energy security, and economic strength in the development of national policy, a view that ". . . has become conventional wisdom. [The commission's] term E^3 has been accepted into the policy lexicon."[42] The commission recommended promoting coordination of E^3 in the Congress and improving the top-level mechanism for such coordination in the executive branch.[43] In regard to the latter, the report recommended that the system be reorganized and integrated through a number of specific changes in the Executive Office of the President, mergers of existing agencies, and consolidations of laboratories of the Environmental Protection Agency.

Long-Term S&T Planning.[44] The report found that devoting more attention to long-term U.S. S&T policy, both within and outside of government, is "critically important in today's rapidly changing, highly competitive global economy" (p. 69). The report recommended that mechanisms for institutionalizing long-term S&T goal-setting should be instituted in the policymaking and budget-setting processes of Congress and the executive branch. Another major recommendation was that 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.

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[41] See the chapter "Environmental Research and Development" and the individual commission report, *E^3: Organizing for Environment, Energy, and the Economy in the Executive Branch of the U.S. Government* (New York: Carnegie Commission on Science, Technology, and Government, April 1980), 19 pp.

[42] Information bulletin., 4.

[43] Carnegie Commission, *$E^{3:}$*, 10-13.

[44] See the chapter "Long-Term Goals."

Science and Technology Shaping the Twenty-First Century[45]

Background of the Report. This is a 1997 White House report highlighting the Clinton Administration's S&T goals and accomplishments. It was required by the National Science and Technology Policy, Organization, and Priorities Act of 1976 (P.L. 94-282), as part of the executive branch's biennial reporting to Congress. The report incorporated key issues and policy goals from two earlier White House reports, *Science in the National Interest* (1994) and *Technology in the National Interest* (1996),[46] as well as current Clinton Administration S&T policies and programs.

The Administration's S&T policy achievements were promoted by examples taken from a wide range of past, current, and proposed programs, as well as by stating the potential importance of those programs in the next century. The entire spectrum of federal S&T policy was described or alluded to in the report, including federal research agency and laboratory activities, programs, and other related policy initiatives.

Key Aspects Regarding the Role of the U.S. Government in S&T Policy. The report covered six broad policy areas: science, technology, national security and global stability, the environment, health, and human resources. Each issue was addressed in a separate chapter

Science. The report takes the position that the federal government's support of basic research is an underpinning for the nation's economic well-being, health, and security (pp. 11-33). It highlights several national science policy goals and achievements since 1993. Those described in greatest detail were sustaining leadership in scientific knowledge, investing in modern scientific facilities and instruments, and "partnering" to advance scientific frontiers. According to the report, the federal role is very broad, yet productive, when it comes to supporting basic research and advancing scientific frontiers. The report contended that federal support of a wide range of innovative and experimental scientific research projects gives the United States its lead in international science awards and honors (for example, in Nobel Prize winners in science from 1993-1996).

However, the report also contended that unless further investment is made, the United States may fall behind other nations that are increasing their national non-defense R&D budgets. The Administration's position was that competitive advantages in the future will accrue to nations through investments that produce new basic knowledge. The report provided examples of how U.S. advances in astronomy, the environment, advanced materials, and nuclear science have provided a wide range

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[45] Executive Office of the President, Office of Science and Technology Policy, *Science and Technology Shaping the Twenty-First Century* (April 1997), 141 pp. Unless otherwise noted, all quotes in this section are from that source.

[46] Executive Office of the President, Office of Science and Technology Policy, *Science in the National Interest* (Aug. 1994), 31 pp.; and Executive Office of the President, Office of Science and Technology Policy, *Technology in the National Interest* (1996), 87 pp.

of benefits to the American people, from new knowledge about human existence to practical applications in medicine.

The chapter on science also addressed the importance of the federal effort to maintain modern scientific facilities and institutions. It report stated that federally funded R&D facilities are among the best in the world. It cited many examples, including facility developments and upgrades at NASA, DOE, NSF, and NIH, where federal investments have paid off. A wide range of scientific partnerships also were noted in the report. This chapter summarized the benefits of scientific partnerships with industry, academia, and other R&D organizations to enable greater leverage of national research investments.

Technology. In February 1993, President Clinton set forth his national technology policy.[47] *Science and Technology Shaping the Twenty-first Century* noted the Administration's accomplishments in a wide range of technology initiatives, both as a direct supporter of technology development and as a catalyst enabling U.S. industry to compete globally (pp. 35-36). To maintain the U.S. technological lead, the report called for the continuation of favorable domestic technology policies as well as, where appropriate, removing barriers to international R&D collaboration.

The report contended that the government has a direct role in providing funding vital to technology invention and innovation. In turn, that has led to the creation of new industries, such as the computer and biotechnology industries. It also has propelled existing industries, such as agriculture and telecommunications, into global leadership positions by creating a favorable environment for technology development. Federal technology policy, either directly or indirectly, has led to advances ranging from frozen orange juice to close-captioned television for the deaf. The report stated that, since 1993, the Administration's economic, regulatory, and trade policies have enabled U.S. industry to develop, commercialize, and otherwise compete in the global economy. In this role, the federal government has removed barriers and streamlined procedures for technology innovation.

The report stated that, through the Advanced Technology Program (ATP) of the Department of Commerce, the Clinton Administration has created successful government-industry partnerships. For example, it cited the Auto-Body Consortium, which has helped the U.S. automotive manufacturing and supplier industries. The chapter also discussed other types of partnerships outside of the ATP. An example is the NASA Aeronautics Enterprise, which has worked with the U.S. aerospace industry to identify high-payoff commercial technologies.

A third area where the Administration cited a successful U.S. technology policy is infrastructure. That includes direct federal support for infrastructure initiatives in information technologies and the Internet (the Next Generation Internet initiative), transportation (Intelligent Transportation Initiative), and navigation (Global Positioning System). The Administration also viewed infrastructure in a larger

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[47] See Congressional Research Service, *Technology Policy Initiatives in the Clinton-Gore Administration,* by Glenn J. McLoughlin and Wendy H. Schacht, Report 93-357 18 March 1993, 48 pp.

context of a networked research infrastructure. In health and medicine, and in standards and measurements, federal investments provide payoffs in direct technology application, and through partnerships (for example, NIH's Cooperative Research and Development Agreements (CRADAs)), that encourage nonfederal institutions to take a more active role.

National Security and Global Stability. To ensure that the U.S. military and the defense community is capable of maintaining the highest level of security and vigilance, the Clinton Administration has called for increased investments in R&D linked to U.S. national security (pp. 57-75). The threat to national security was defined not only in terms of warfare and the need for advanced weapons, but in terms of nuclear proliferation and terrorism. Thus, the federal S&T role is not just limited to the traditional one of supporting DOD R&D, but also includes a federal role in supporting and encouraging S&T initiatives in fields related to broad national security goals.

The Administration report called for a radical restructuring of U.S. defense S&T policy. There are three prongs to this federal role: acquisition reform of the U.S. military (purchasing the highest quality technology at lowest cost), promotion of dual-use technologies (including dual-use R&D, integrated production, and insertion of commercial technologies), and increasing military/civilian technology prototypes.

In nuclear proliferation, the report called for a wide range of efforts in which the federal role is to reduce existing threats and stem the spread the weapons of mass destruction. Those efforts have included new bilateral and multilateral proliferation agreements, enhanced global cooperation, and new technologies for monitoring and verification. The lead agencies have been DOD and DOE.

The report stated that the U.S. infrastructure, from transportation to telecommunications, is at risk from terrorist attacks. The Critical Infrastructure Protection Commission was created by the President in 1997 to develop a national policy addressing that risk. Several broad S&T initiatives to promote global stability also were included: strengthening scientific ties with other nations, fostering global partnerships in science and technology, applying U.S. advances in health and medicine to reduce or eliminate disease, and using S&T agreements to help countries maintain democratic advances (such as in South Africa).

Environment. The Administration's report cited Vice President Gore's long-standing interest in environmental policy to improve the standard of living and well-being of all people (pp. 77-93). The policy goals and achievements listed in this chapter reflect the environmental policy developed by the Clinton Administration since 1993. That environmental S&T policy is defined by the Administration to include a wide range of health, biodiversity, ecosystems, and global climate change issues to promote a sustainable future for the world's environment.

The report contended that only the federal government can provide the broad, overarching S&T policies and actions that will ensure a cleaner environment. U.S. industry, academia, and state and local governments may have an interest in some environmental issues, and the report cited a variety of partnerships with those groups and the federal government. To sustain a healthy and safe future, the Administration contended that federal policymakers must confront a variety of local, regional, and global environmental challenges within a comprehensive policy framework.

In this chapter, the Administration described the environmental challenges addressed by federal policies and programs. They included maintaining biological diversity and protecting endangered species; safeguarding water resources; improving air quality; reducing (and ultimately eliminating) exposure to toxic substances; limiting the impact of natural hazards (for example, hurricanes); reversing stratospheric ozone depletion; and understanding, mitigating, and adapting to climate change.

This chapter provided an extensive list of federal programs addressing those issues. The list includes DOE, EPA, Department of the Interior, NASA, NOAA, NIH, and NSF programs for developing clean alternative energy, disposing of toxic waste, maintaining wetlands, improving satellite monitoring of weather patterns, using computer modeling and simulation to forecast global climate change, assessing endocrine disruptions in humans and wildlife, and supporting basic research initiatives where industry and other nonfederal institutions are not undertaking research and development. Among the international programs is a U.S.-Canada-Mexico public partnership addressing ozone depletion.

Health. The report cited the long history of the federal interest in improving the health of the nation's citizens through investments in science and technology (pp. 95-115). The federal role in biomedical research is primarily undertaken through NIH's programs addressing health and disease issues facing Americans. However, other federal agencies, such as USDA, NSF, NASA, EPA, CDC, and the Departments of Energy, Defense, Veterans Affairs, and Commerce, support research in health and food safety.

In biomedical research, the federal R&D effort supports NIH programs focused on understanding, treating, preventing, and curing diseases such as cancer, HIV/AIDS, and Alzheimer's disease, as well as emerging diseases such as Ebola Hemorrhagic Fever. The NIH also supports research in genetic mapping and is a significant supporter of neuroscience research as part of the 1990s "Decade of the Brain" (p. 103).

In food and health, the report provided several examples of ongoing federal efforts to improve food safety, nutrition, and production. They include federal programs that fund research in sanitary standards and improve public knowledge of nutrition. Agricultural S&T issues cited in the report include direct federal S&T policies, such as USDA programs in animal health and husbandry, and broader policies that enable greater advances in agricultural development, such as harmonious trade efforts. The report also cited federal programs in both basic and applied agricultural research as part of the larger federal health and safety R&D portfolio.

Human Resources. This chapter outlined current federal efforts in a wide range of S&T education, training, and literacy issues (pp. 117-134). It described the federal policies and programs supporting S&T human resources both by direct support and funding to improve learning and knowledge, and policies that create a more informed population. All of the major federal research agencies have contributed to those policies.

The federal role in human resources development can be likened to three concentric policy "rings." At the center are federal policies that are intended to create and maintain world-class leadership in science and technology. At the core of that policy thrust are the university research and federal laboratory systems, which receive direct federal funding and support. A part of that thrust is federal policies to improve the international performance of U.S. students in mathematics and science. A second policy ring is federal support for an educated technical workforce. The report cited several Department of Education programs to support that policy goal, as well as partnerships with industry and the states to develop a workforce capable of dealing with advanced technologies in the 21st century. The third policy ring is to expand the S&T literacy of the entire U.S. population. The federal role extends from child care programs that develop reading and mathematics skills to programs that support adult learning and life-long education.

The report viewed all of these human resources policies and initiatives as important to the future of U.S. science and technology. All three have broad, national objectives, particularly in developing a technical workforce and in encouraging a scientifically literate population. In those two areas, human resources policies are combined with Administration science and technology policies described in the first two chapters of the Administration's report, and alluded to in subsequent chapters as well.

Findings and/or Conclusions. In the report, there are two overarching S&T roles for the federal government. One is a direct role, in which government support of R&D promotes, supports, and ensures the health, welfare, security, and economic prosperity of the American people. That role is advanced through the federal agency missions in science and technology, the federal laboratory system, and support of university research. The other role is that in which the federal government serves as a catalyst, enabling nonfederal S&T institutions to flourish. In that role, the federal government fills a broader, but — according to the Clinton Administration — no less important position. The role includes supporting S&T education and training, creating favorable tax policies, providing capital investment, and creating R&D spin-off benefits.

The report contended that both roles are critical and — correctly according to most science policy analysts — that many of S&T initiatives cited in it are part of an historical federal role going back several decades or centuries (for example, agricultural research). Still, since the entire report was about the role of the federal government in science and technology, there are virtually no policies, programs, or activities discussed in it that fall outside either the direct role of the federal government or its indirect role as catalyst. When both roles are combined, the tone of the report implied an activist federal S&T policy, regardless of which role is taken.

Investing in Innovation: Creating a Research and Innovation Policy That Works [48]

Background of the Report. This book was the culmination 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, DC, on November 18-19, 1996.

The book sought to shed light on the debate that emerged between the Republican Congress and the Clinton Administration regarding the appropriate federal role in fostering technological innovation. The authors argued that bipartisan consensus for technology policy requires a recognition that science and technology are deeply intertwined and often indistinguishable from each other, in contrast to research and development, which are quite distinct activities calling for different institutional settings and different expectations from their sponsors. According to the authors, there is basic agreement between Congress and the Administration regarding the federal role in the support of basic research and the education of future scientists and engineers — public activities that benefit both the public and private sectors. However, much intellectually exciting and economically useful research lies between the categories of basic science and commercial product development (which Congress and the Administration agree is primarily a private sector responsibility).

Branscomb and Keller argued that, when political debate divides the world of R&D into basic scientific research on the one side, and everything else from applied research to product development on the other, the debate loses sight of a huge and important "gray area" of research. The authors refer to this gray area as *basic technology research,* in which both the public and private sectors have an interest (p. 467). The book concluded by developing a set of principles that outline what the federal role should be in supporting need-based basic technology research.

KeyAspects Regarding the Role of the U.S. Government in S&T. The report concluded that innovation is the product of intellectual creativity and broad-based collective efforts. The authors 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. They contended that the United States requires a carefully crafted, broadly supported approach to this global challenge. The final chapter of the book 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. In that light, the book outlined six principles that reflect the view that the most appropriate and effective role for the federal government is to ensure that organizations and individuals have the knowledge, skills, and incentives to generate private investment in innovation. The authors stated that these principles are entirely

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[48] Lewis M. Branscomb and James H. Keller, eds., *Investing In Innovation: Creating a Research and Innovation Policy That Works* (Cambridge: MIT Press, 1998), 516 pp. All quotes in this section are from that source.

consistent with the government's central economic strategy to encourage savings and investment, rather than to drive consumption.

Findings and/or Conclusions. Branscomb and Keller noted the six principles described next that are intended to provide a clear framework to aid in program and policy development. The principles are intended to inform decisions and provide a litmus test for program evaluation and improvement. Before any federal money is committed for basic technology activities, one should ask such questions as, Is there a significant public problem that must be addressed by the federal government? Are there no other entities, such as the private sector, willing to offer solutions to the problem? If not, does the government have the skills, experience, and political legitimacy to bring about the desired results in a manner acceptable to all of those affected? Finally, they noted that these questions are asked in an atmosphere of finite resources in which priorities must be set and difficult competing choices made (pp. 485).

Principle 1: Encourage Private Innovation through Public-Private Partnerships. The government should promote private investment to spur economic growth, improve living standards, and accomplish important governmental 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 create markets for nonmarket entities, such as tradable permits for sulfur emissions, rather than direct government funding of research and development. However, policymakers should realize that private firms underinvest in longer-range research and in research to meet public purposes. Therefore, the federal government should share in the cost of developing technologies that can meet the needs of both the public and private sectors. The book 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 authors suggested that industry's cost-sharing requirements should be raised as the technologies being developed get closer to primarily commercial applications.

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

With respect to direct or matching support of federal research, the authors recommended that the federal government continue to focus on traditional, basic scientific research and "basic technology research," both of which produce benefits far beyond the fair returns on investment accruing to research performers in the private sector. Basic technology research includes activities that involve investigating fundamental processes 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" (p. 468). Further, companies have become more reluctant to put resources into basic technology research that is long-term and high-risk, or both, even though that research could eventually pay handsome returns to society as a whole. The book noted that more narrowly targeted or short-term research, with clearly defined goals, such as 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 authors 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. That 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 book 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: Facilitating Access to New and Old Technologies. Promote effective use and absorption of technology across the economic spectrum, with special attention to the roles 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, mainly 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. That 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.

Two programs of the Department of Commerce were discussed. The National Institute of Standards and Technology (NIST) Manufacturing Extension Partnership (MEP) program was offered as an effective model of federal-state partnership in technology diffusion and regional economic development. The authors also suggested that the states should play a role in shaping NIST's Advanced Technology Program (ATP). For example, ATP should no longer focus its grants on a single company, but should focus its resources on establishing multicompany 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: Research and Innovation Policy Is More than R&D. Utilize the full range of relevant policy tools (for example, tax incentives, regulatory reform, standards, and intellectual property rights), recognizing that different industries, technologies, and regions may call for different mixes of those policy tools.

A "one size fits all" technology policy is almost certain not to be successful. Rather, the book noted that every industry is different and government agencies must be sensitive to those differences, which require different policy approaches 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 cross-licensed their technology internationally. Biotechnology companies draw directly on cutting-edge 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, in addition to those mentioned above, facilitation of standards development; federal procurement; antitrust law and competition policy; and consensus building and policy analysis, such as 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 that 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 them. 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 authors noted that resolving trade conflicts tends to receive more public attention than investing in transnational collaboration and cooperation in the development of new science and technology, although the latter often produces more benefits to the U.S. economy than the former. According to the book, the Global Information Infrastructure (GII), in which U.S. firms and institutions enjoy a commanding lead today, is an excellent example of the role of U.S. leadership in developing a harmonious international environment.

Principle 6: Improve Government Effectiveness in Policy Development. 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 other policies recommended in this book. American science and technology thrive because they are 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 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 to be judged. The book 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 deauthorize those initiatives. The authors hoped that all sides will show more patience during the next four years.

The Future of the Government-University Partnership[49]

Background of the Report. There is widespread concern among both faculty and students in the nation's research universities about the future of research support from the federal government. One manifestation of that concern is a desire to revisit the principles on which the partnership between the government and universities has been based since the end of World War II. While there has been much work over the last several years to articulate new principles, no consensus has emerged. This conference was held with the hope that it could move toward such a consensus.

Opening remarks were made by Representative Vernon J. Ehlers and Representative Lynn M. Rivers about what each hoped to get out of the conference. Rep. Ehlers listed several desired outcomes of the conference that would prove useful for policy action. In particular, he hoped that it would serve to begin development of a new model for university-government relations. Representative Rivers offered several issues that she hoped would be addressed, including the direction the nation should move to ensure a productive academic enterprise and a healthy economic future.

The conference did not explicitly address the role of the federal government in R&D beyond the discussion of the university-government partnership. Nevertheless, references to that role during the conference, and certain themes about that role did emerge. This section summarizes those themes.

Key Aspects Regarding the Role of the U.S. Government in S&T. Conference participants discussed the character of R&D performed in academia, federal support of university research, the government/university partnership, and organizational and management issues.

Character of R&D. There was general agreement among the participants that the federal government should support long-term, fundamental research. One speaker characterized such research as that which is not "economically feasible" (p. 111). As justification for such research, the conference agreed that new knowledge

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[49] Gary D. Krenz, *Proceedings of the 1996 Jerome B. Wiesner Symposium: The Future of the Government/University Partnership* (Ann Arbor: University of Michigan, 1996), 251 pp. All quotes in this section are from that source.

was fundamental to advances in the nation's well-being, and that fundamental research was the primary source of that new knowledge. Some of the participants also asserted that the government might have a role in supporting midterm research. This type of research was defined as midrange, precompetitive research. One speaker noted that such research, which had been performed mainly by industry and which provided the main connection between the knowledge base and products, has all but disappeared because of global economic pressure that forced industry to concentrate on new product development.

There was also substantial support among the speakers that a critical contribution of the university-government partnership is its "nurturing and maintaining" (p. 53) of the human resources needed for technological advancement. Therefore, support of education through the research process is an important responsibility of the federal government.

Federal Missions. Very little was said about federal funding of research that supported specific federal missions. The conference, however, strongly endorsed support of university research by the federal government in the context of the university-government partnership. The only other reference to mission-related R&D was by one speaker who argued that policymakers do not adequately understand the importance of the contribution to general research and education of the R&D funded by the federal mission agencies. Although that statement implied that federal funding of mission-oriented R&D should continue, there was no discussion about that proposition.

The Government-University Partnership. The participants spoke of a government-university partnership as formed from the principles set forth in the 1945 Vannevar Bush report.[50] Those principles were that the federal government would provide support for the performance of fundamental research at the nation's universities, and that research, in turn, would produce the knowledge and trained people that would lay the foundation for greater national well-being. One speaker argued that the partnership has been a major factor in the nation's success over the last 50 years. An important theme of the conference, however, was that a new model for that partnership is needed. Although some argued that many of the principles behind the Bush model were still valid, most felt that a new science policy was needed to guide the partnership in the future.

Little was said about other forms of government partnerships. One exception was a statement by one speaker noting the recent establishment of several programs supporting government-industry partnerships performing generic, precompetitive research. He argued that those partnerships were an important new development in the nation's science and technology policy.

Organizational and Management Issues. Most of the discussion in the conference about the federal role in R&D concerned broad management issues. In particular, several participants spoke about actions the federal government could take to reenergize the university-government research partnership.

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[50] Bush, *Science — The Endless Frontier*.

One speaker suggested that the government's role in the partnership is the general allocation of the funds and the establishment of the regulations and guidelines — for example, intellectual property — under which the research is to be performed. He went on to argue that, in carrying out that responsibility, the federal government should develop a more predictable and flexible process for determining funding levels, particularly with respect to large projects. He also asserted that a more efficient, less burdensome administration of regulations would help "reduce disincentives to research" (pp. 142-143). That point was echoed by other participants who noted that the growing load of regulations have added to the cost of doing research and have created large bureaucracies in both academia and government. Caution was raised by one speaker, however, who argued that while reform of regulation of research is needed, universities must be accountable to the public.

Another recommendation was that the federal government pay the full cost of performing research that it funds. One speaker noted that there is an increasing tendency of federal agencies to fail to pay the full costs of research — primarily through reduction in indirect cost rates — forcing universities to meet those costs with funds that should be used for teaching. At the same time, as another speaker pointed out, universities have a major responsibility in seeing to it that costs are contained. One speaker, however, stated as arguable the notion that universities are not doing enough to contain costs, thereby restricting access by nontraditional student populations.

Many participants made the point that research and education need to be more closely integrated. One speaker asserted that there will need to be more emphasis on education as one of the two critical outputs from universities. This speaker noted that many NSF efforts are aimed at strengthening the connection between research and education, including a proposal to recognize research universities that have done an outstanding job of combining research and education. There was a strong suggestion from those remarks that an important federal role is to see that a tighter connection is made between education and research.

A last point concerned ways to increase public support of science and technology. The participants agreed that without such support, sustaining the government-university partnership will be very difficult, if not impossible. Many speakers emphasized that, to gain that support, it was necessary to make clearer to the public the importance of science and technology to the well-being of society. They argued that both partners — universities and the government — have a responsibility in undertaking that task.

Findings and/or Conclusions. The major theme emerging from the conference was that the research partnership between the federal government and universities must be maintained for the benefit of the nation. Doing so, however, will require significant changes by both partners to deal with changing conditions brought by the end of the Cold War, constraints on federal spending, and uncertainties about public support of university research.

A number of other conclusions can be drawn from the points made at the conference. First, federal funding of fundamental research should continue and the primary recipient of those funds should be universities. Second, the government role in the partnership should not be too restrictive. That is, the government should set broad priorities for allocation of the funds and avoid excessive regulation. Third, public support is critical to the success of the partnership. The public must be made more aware of the importance of science and technology to national well-being. At the same time, universities and the federal government must pay more attention to public concerns. Finally, universities must give a higher priority to education. Much public concern appears to be based on a belief that universities have put too much emphasis on research, to the detriment of education.

Effective Partnering, A Report to Congress on Federal Technology Partnerships[51]

Background of the Report. In conjunction with the responsibility of the Undersecretary of Commerce for Technology to serve as an "advocate for innovation and industrial competitiveness,"[52] the Office of Technology Policy (OTP) issued a report detailing the evolution of public-private cooperation in the areas of research and development. The study analyzed the change from government as the primary customer of federally funded R&D to government as a "partner with the private sector in developing and deploying new commercial technologies that fulfill [federal] mission objectives and enhance U.S. industry's market strength" (p. 20). Following World War II, the assumption was that technology, developed to meet federal mission requirements, eventually would find applications in the private sector without any formal efforts. However, that was not the case and, in the early 1980s, several new programs were implemented to actively commercialize government technologies. The approach in the 1990s has been to facilitate partnership, between the public and private sectors, where all participants develop innovations necessary for a global economy. Such changes indicate the existence of a new "paradigm" in which government programs reflect increased business- sector involvement in federal efforts to develop and adopt new technologies. While the amount of federal funds spent on these activities is small in comparison to total U.S. R&D investment, the leveraging of public and private financing has an economic impact beyond that of each separate investment.

There are several key elements of the new paradigm according to the OTP report. Collaboration maximizes the return on R&D investment by focusing on projects with potential for economic growth, job creation, and improved quality of life. Programs that display flexibility, predictability, and stability allow the government to be a "better partner" with the private sector. The increased role of the business community in projects, from concept to execution, provides more opportunities for economic growth through technology commercialization. Cost-sharing gives the private sector a greater stake in the successful operation of

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[51] Department of Commerce, *Effective Partnering: A Report to Congress on Federal Technology Partnerships* (1996), 76 p. Unless otherwise noted, all quotes in this section are from that source.

[52] Department of Commerce, National Institute of Standards and Technology, *1999 Budget Highlights (February 1998), Internet site*, [http://www.nist.gov/public_affairs/budget/99budget_hilite.htm].

government programs, while limits on the length of participation ensure that unsuccessful activities will be terminated.

Key Aspects Regarding the Role of the U.S. Government in S&T. That there is an important role for the federal government in maintaining competitiveness is underscored throughout the report. Although the private sector has primary responsibility for the health of industrial innovation, government has an interest in maximizing "the economic benefit to society of the tax dollars invested in mission R&D" (p. 37). It is through collaborative efforts that federal investments of time and resources become more effective.

Partnerships allow for the creation of a critical mass of skills, knowledge, and resources that permit more technologically challenging work to be undertaken beyond the individual capabilities of each party. For the federal departments and agencies, cooperative ventures move state-of-the-art information, expertise, and technologies from the private sector to the government for use in meeting mission requirements. Collaborations help decrease the costs of large, expensive projects where there is both public and private sector interest by offering and facilitating commercialization opportunities beyond the original application of the research and development.

The economic well-being of the industrial community is also of concern to the government. The process of innovation typically is very costly and time consuming, and the outcomes often are uncertain. Partnerships along with other technology policies are intended to alter the balance between risk and reward, so that costs and uncertainty become acceptable and there is additional incentive to undertake R&D. Collaborative activities are designed to "directly catalyze private sector investments in new technologies," (p. 46) and foster the "creation of business and research synergies" (p. 54). The evidence of strong industry support for cooperative R&D efforts is reflected in the extent of participation and the degree of cost-sharing. "In total, the private sector has invested $3 billion in cofinancing for technology partnerships with the U.S. government" (p. 63). There is great potential for expanded participation by the business community; there also is interest in other government initiatives to spur innovation. Those initiatives include product liability reform, tax changes affecting capital formation, standard-setting regulations, and other regulatory policies. Such efforts should be designed to reduce uncertainties and costs tied to investments in research and development.

The new "paradigm" of public-private partnerships includes many activities. Agencies are placing greater emphasis on commercialization potential in selecting projects to fund. Nonfinancial assistance to small firms is being offered in conjunction with ongoing R&D programs. Efforts are being made to strengthen the private sector's intellectual property rights associated with collaborative ventures. "To maximize the commercial effectiveness of partnerships, private sector partners need both clear title and freedom from potential conflicts in product pricing and royalties" (p. 57). Federal agencies also are attempting to build speed, flexibility, and predictability into the partnership programs. That is in conjunction with increased private sector participation in the development and implementation of relevant government programs.

Findings and/or Conclusions. The results of government-industry partnerships, while apparent, are hard to assess quantitatively because of difficulties in measuring the outputs of public and private investments in R&D. Currently, the executive branch is developing new methodologies to calculate the effects of research and development on the economic well-being of the nation. However, there are documented "interim measures of success" identified in the Office of Technology Policy report. Increased licensing between federal laboratories and the private sector, as well as between universities and industry, demonstrates commercialization potential arising from collaborative work. Twenty-seven percent of Small Business Innovation Research (SBIR) program projects have resulted in product sales in both the commercial and governmental markets. An increased number of cooperative research and development agreements (CRADAs) have been negotiated and are operational. The Advanced Technology Program (ATP) of the National Bureau of Standards and Technology (NIST), in the Department of Commerce, has reported accelerated development of new technologies, expanded technical capabilities, and reduced time to market.

The OTP report offered several recommendations to facilitate partnerships, as summarized next.

Make Partnership Opportunities More Accessible and Easier to Identify. The decentralized nature of federal R&D has made it difficult for the private sector to identify appropriate partnership opportunities and relevant intellectual property. Increased information dissemination could help remedy this situation. The government can act as a catalyst, tying sources of private-sector funding and business expertise with companies that need such resources. It can also promote expanded professional interactions including "fellowship programs, work details, procurement contracts, professional seminars, or joint research ventures" (p. 67). Additional interagency coordination of research can assist in wider dissemination of partnership opportunities by providing public information on governmental interests and projects. Federal collaborative efforts with consortia and other "umbrella" organizations can "multiply" the effects of the work by involving several companies and universities. Providing effective and unambiguous intellectual property protection can overcome obstacles to industry participation in public-private partnerships.

Be a Better Partner: Improve Speed, Flexibility, and Predictability. One of the impediments to expanded collaborative work is the time necessary to establish joint ventures and the inflexibility of the arrangements, once they are negotiated. "The goals of the negotiations of the partnership agreement should be to enable the parties to reach agreement on mutually beneficial terms in the least possible time while spending the least possible resources" (p. 69). Funding must be available in an expedient fashion and efforts must reflect the interests of firms in controlling the intellectual property generated from substantial private-sector support.

The Office of Technology Policy report recommended that partnership agreements be easier to negotiate. Involving intermediary organizations in the process can be helpful. The government needs to understand the differing research objectives of members of a consortium involved in a public-private collaboration. The authority to use flexibility in administering cooperative ventures minimizes burdens on the participants, as does predictability in partnership arrangements among agencies and laboratories. Negotiations are time and resource intensive, so some conformity (paired with flexibility) can decrease uncertainty in the business community.

Help Small Businesses Secure Necessary Business and Financial Advice from State Programs and Private-Sector Sources. Partnerships with small firms that have strong research capabilities can be very productive. However, those companies often do not have the business expertise necessary to commercialize the results of research and development. A concerted, comprehensive effort on behalf of the federal government is necessary to assist such firms in obtaining the resources to bring technologies to the marketplace successfully.

Further Increase the Private-Sector Role in Project Definition and Selection. Private-sector participation in collaborative efforts to meet agency mission requirements is important to improved partnering and does not compromise the integrity of the government's research responsibilities. Without such interaction, it is extremely difficult to move federally funded R&D into the marketplace. As stated in the OTP report, "the point is not to take the agency beyond its legitimate research mission but to ensure that, within the scope of that mission, the agency considers the private sector's interests in defining the areas in which it will solicit funding proposals" (p. 74).

Shift to Commercial Financial Management Practices. The implementation of federal cost-accounting principles is a major obstacle to private-sector partners because it is expensive and unfamiliar. The methodology was developed to meet the needs of the government as customer, rather than as partner. Agencies should demonstrate flexibility in moving toward commercial financial management practices when negotiating the requirements of a joint venture. According to OTP, "the experience of ATP and the other partnership programs with private sector partners indicates that corporate fraud or misuse of funds is extremely unusual" (p. 75).

Continue Developing an Integrated System of Measuring Program Results. Increased accountability of government programs is in the interest of both Congress and the Administration. However, measurement of the results of federally supported R&D currently is a difficult and inaccurate undertaking. Thus, further efforts must be taken to assess program outputs, both the immediate effects as well as the long-term, widespread economic impacts of such activities. The agencies need to develop and implement a comprehensive system of measurement. Such an effort will require the involvement of industry and academia.

Downsizing Science: Will the United States Pay a Price?[53]

Background of the Report. This book reviewed the benefits of scientific research to society and the economy, traced downsizing in federal support for

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[53] Kenneth M. Brown, *Downsizing Science: Will the United States Pay a Price?* (Washington: The American Enterprise Institute Press, 1998), 151 p. Unless otherwise noted, all quotes in this section are from that source.

research, and offered recommendations for forestalling cuts and for an appropriate federal role to support academic research, federal laboratories, and industrial R&D.

Key Aspects Regarding the Role of the U.S. Government in S&T. Studies by leading economists, according to Kenneth M. Brown, show that scientific research plays a crucial role in enhancing the productivity of the U.S. economy, in promoting long-term economic growth, and in providing social benefits. According to Brown, economists have concluded that technological change accounts for between 80 and 90% of growth in output per worker over the long term, but results are less clear about the effect of research on innovation.

Although some consider federal support for science to be "a blip on history's radar screen," (pp.15-16) because of its relatively short history and because it is a decreasing percentage of national R&D support, it is crucial for some federal missions and for academic research. However, Brown said that federal funds for science peaked in real terms ten years ago and have drifted downward since (p. 5). Future real dollar reductions in federal research funding are expected in defense R&D and in all areas of civilian R&D, except for the National Institutes of Health and the National Science Foundation. The reductions will occur because of firm discretionary spending caps and as more of the discretionary budget goes to support increases in entitlement funding as a result of an increasingly large aging population. Pressure on the budget will increase if there is an "unanticipated economic downturn." Additionally, "the current outlook [reduction] for science is all the more unsettling because it comes after rapid expansion . . . . Over the . . . period 1953 to 1990, average annual growth [of R&D funding] was 4.8 percent, about two percentage points above the growth of the economy as measured by the gross domestic product" (p. 13).

Additional downsizing in federal science funding would be risky, according to Brown, since the returns on investment in research are so large. "The empirical evidence gives little guidance, though, as to whether the science budget should be $50 billion or $150 billion" (p. 28). It is likely that no other area of federal investment provides such high social benefits as research and development. Even though the best estimates of the average rate of return on science spending suggest that it is around 50%, that does not prove that there should be more spending. Brown cited several different economic studies that, by his calculations, show benefits of R&D investment of about 8% to 10% of gross domestic product (GDP) annually. Another way of calculating the effects of R&D is on its contribution to economic growth. Brown wrote,

> Another rough calculation: R&D is 2.6 percent of GDP. Suppose we make a massive 20 percent cut in R&D, which would equal 0.5 percent of GDP. If the rate of return on the lost R&D had been 50 percent, then we would lose 0.25 percentage point of growth each year, a fairly large amount in relation to the nation's long-term growth of about 2.5 percent. Certainly, anyone who could devise a feasible policy that would add 0.25 percentage point of economic growth would be an economic miracle worker (p. 26).

Furthermore, concern about the negative effects of downsizing science needs to account for the fact that many benefits of science are not captured in the national income accounts — for instance, the better health and longevity generated by biomedical research. The effects of downsizing also need to account for the benefits lost — the new knowledge not discovered.

Federal budget cuts eliminating "bad science" projects might help solve the problem of budget reductions, but seem to be infeasible politically. Other major supporters of research — foundations and the private sector — will not make much of a contribution to replacing federally funded research dollars. Foundations devoted only a small amount of money — just about $250 million in 1993 — to scientific research. While federal funds have decreased in real-dollar terms and as a proportion of total national support for R&D, industrial spending for R&D has increased. In the past, industry funded less than 50% of national R&D. Today, it funds about two-thirds, totaling about $130 billion in 1997, while the federal government funds about $75 million. However, industrial support of basic research has declined, implying that the federal government should fund risky fundamental science, since private companies could not fund fundamental research on the scale funded by the federal government.

According to Brown, there is a "vital but limited role for government" in support of research (p. 44). He rejected the views of some economists who "question any role at all for the government in promoting science." They include economist William Niskanen, who prefers "to augment private R&D expenditures through the tax system, by a tax credit for research and experimentation [and] matching grants as a means of inducing more government research without putting government completely in charge of selecting specific research projects" (p. 52). He also disagreed with Terence Kealy, who, he said, argues "that science would be adequately supported by private means without governmental intervention" (p. 52). He said that to support his views, Kealy used selective examples of failed projects that met his criteria but did not represent a full spectrum of the history of projects. He also disagreed with the view of Charles Murray, who he said "would wipe out all subsidies for scientific research, leaving only enforcement of patent law as the sum total of science support" (p.53).

Government funding should focus only on research that the private sector would not fund. More attention should be given to allocating funds and determining priorities in an increasingly constrained federal research budget. It is not easy to use objective criteria to evaluate or assess the value or outputs of federal research. The Government Performance and Results Act (GPRA, P.L. 103-62) requires that outcomes of federal research programs be evaluated. Such evaluations are expensive. "To date, no GPRA analyses have been satisfactorily completed" (p. 130).

The economic theory of "public goods," according to Brown, provides principles that guide priority setting by developing three "necessary conditions for legitimate governmental funding." Those are,

- The research must have a reasonable chance of producing benefits that outweigh its costs. These must be broad social benefits (rather than benefit just to a particular firm).

- The research would not be performed in the absence of governmental support.

! The federal agency must be able to fund or perform the research efficiently. (See chapter 5, pp. 44-54.)

These three criteria apply equally to research grants, contracted research, and "mission research performed by government laboratories" (p. 48).

Findings and/or Conclusions. The difference between mediocrity and excellence in science amounts to "low billions" of research support dollars annually. Reductions in federal science funding would not cause immediate measurable showdowns in productivity growth, but, inevitably, some needed research would never be conducted. The biggest impact would be on the nation's universities, which "will be noticeably different after ten years of diminished federal funding." Well-endowed research universities may not suffer much, but, because of reductions in the less prominent universities, fewer Ph.D.s will be trained and more U.S. students will have to go abroad to find expertise in certain fields. As U.S. universities obtain more funds from industry, or seek to earn more from profit-oriented consortia, the "wide-ranging social benefits of freely available research may be compromised" or scientific research in academia may become more short-term. Nevertheless, commercially supported academic research "seems clearly preferable to simply letting academic research shrink . . ." (p. 90-91).

The federal government should "target federal funds more effectively," (p.129) eliminate questionable programs, and "increase spending by around 3.0 or 3.5 percent annually (in real terms)" in order to "support science at a level which is acceptable" (p. 128). This is within the nation's reach, but living within tighter budgets means that the nation will have to "live within the following guidelines."

"Target federal funds more effectively". "If we could selectively target the least efficient [federal government] subsidy programs for elimination, then downsizing might not be so harmful. Unfortunately, science budgets are not established in that way, nor is there any actual authority that systematically reviews R&D programs with efficiency as a key consideration" (p. 54). Stability in federal funding also is important. "The process of allocating federal funds for science and technology . . . needs to be made more coherent, systematic, and comprehensive" (p. 54). Brown described the proposal in the 1995 National Academy of Sciences report, *Allocating Federal Funds for Science and Technology*,[54] as a "reasonable attempt to organize science budgeting." It called for development of a federal science and technology (FS&T) budget, which would "exclude funding of production engineering, testing, and upgrading of weapons systems . . ." (pp. 129-130).

"Nurture — but do not directly subsidize — industrial R&D". Industrial research is well-funded by industry but is shifting away even more from fundamental research to applied research. Some existing federal programs directed at industrial research have a strong tendency to displace what industry could have done on its own. The federal government should not fund applied research projects that industry

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[54] National Academy of Sciences, *Allocating Federal Funds for Science and Technology*.

will fund and should eliminate those programs that are inefficient, such as the Department of Commerce's Advanced Technology Program, which now appears to displace private-sector funding. "Subsidies are justified only to the extent that they buy social benefits. Benefits that accrue only to the firm are not legitimate goals for federal subsides, if one accepts the market-oriented framework for economic policy." (p. 106) Brown endorsed the recommendations of the Academy report on *Allocating Federal Funds for Science and Technology* that

> "The government should encourage, but not directly fund, private-sector commercial technology development, with two limited exceptions:

- Development in pursuit of government missions, such as weapons development and space flight; or
- Development of new enabling, or broadly applicable, technologies for which government is the only funder available" (p. 106).

The government should reduce actions by regulatory agencies that inadvertently reduce the effective rate of return on industrial research. If industrial R&D funding slows down, we need to look "to the more subtle and indirect causes, such as tax policy . . . federal regulations" and the like. "The whole range of regulations, health care policies, and complex legalisms that surround pharmaceuticals, for example, probably do more to affect the rate of return on R&D than ten Advanced Technology Programs would" (p. 131). Also, the federal government can aid industry by ensuring adequate funding for fundamental scientific research at universities, since such research is necessary for innovation.

"Rationalize the roles of federal laboratories". Federal laboratory missions need to be adjusted by Congress, following the end of the Cold War, to realign and focus the laboratories' missions. "A clear agreement on precisely what role the labs should play in the nation's research enterprise is lacking, and pork barrel considerations are likely to warp any national plan that may emerge" (p. 78). But the laboratories' main functions in energy, defense, and related mission objectives, in public health, and the like, seem appropriate. "The missions would entail a certain amount of fundamental research, but not on a large-scale transition into research that is best performed at universities" (p.79). He sees the laboratories performing "applied research that nonetheless has broad benefits and which for that reason companies are unlikely to perform," including "advanced computing techniques or intelligent robotics or new manufacturing processes and advanced materials" (p. 79). However, laboratory performance now does not meet the requirements of the third criterion: Federal laboratories need to be managed more efficiently. He disagreed with recommendations to create a commission to target laboratories for elimination. "The survival of a highly valuable but misused resource is at stake" (p. 131). What is needed is a commission to study the role and missions of the laboratories.

"Recognize the growth of science worldwide and develop policies to take advantage of it". Internationally, the United States now leads the world in science, as it has since the end of World War II. The downsizing of U.S. scientific research funding is occurring at a time when other nations are increasing theirs. These two factors combined would, in the future, force U.S. scientists to cooperate more with scientists in other nations and to pay more attention to the scientific results generated by other nations. Leadership in science "does not make a lot of sense as a goal of science policy" (p. 131). The nation needs to be more interactive with the countries that are enlarging their scientific activities. "[W]ith the global expansion of science bringing rapid growth in the world's knowledge base, [w]e should welcome this explosion of new knowledge as a benefit to the United States, not fear it as a threat" (p. 124).

"Protect federal support for academic research". The federal government plays a crucial role in support of university research, which is especially significant because universities are the nation's largest performers of fundamental research, and they train scientists and engineers. On average, universities receive about 60% of their research budgets from the federal government. Thus, they would suffer large reductions in their research budgets with more downsizing in federal R&D budgets. That would hurt the nation's potential to innovate and cause the most serious long-term consequences (chap. 8). Industry and other sources will not be able to replace federal support for university research if it is downsized; therefore, federal funding needs to be protected.

Brown concluded by noting that while research on the "measurement of the economic effects of R&D" appears to have "gone about as far as it can with the existing data, which are virtually mined out," more research is needed on the theory of intellectual property and its applications, especially in a time when it is likely that public resources for science will be limited (p. 132).

Appendix: Acronyms of Some Federal Departments and Agencies Referred to in This Report

CDC — Centers for Disease Control and Prevention

DARPA — Defense Advanced Research Projects Agency

DOC — Department of Commerce

DOD — Department of Defense

DOE — Department of Energy

DVA — Department of Veteran Affairs

EPA — Environmental Protection Agency

NASA — National Aeronautics and Space Administration

NIH — National Institutes of Health

NOAA — National Oceanic and Atmospheric Administration

NSF — National Science Foundation

NIST — National Institute of Standards and Technology

USDA — Department of Agriculture