U.S. SCIENCE AND TECHNOLOGY POLICY: ISSUES FOR THE 1990s

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Preface

This review of issues in U.S. Science and Technology Policy was prepared for a study of Science and Technology Policy of Brazil, being conducted under the direction of Prof. Simon Schwartzman of the Fundacao Getulio Vargas, and supported by the World Bank. This analysis focuses on the science and technology issues as they relate to the changing political and economic environment in the U.S. While this paper does not attempt to evaluate S&T policy issues in Brazil, the possible impacts of policy changes in the U.S. on Brazil are noted.

The paper does not deal in detail with a number of "science for policy" issues, such as health care, environmental preservation, defense technology, education, or the cultural value of science, even though these are very important issues in the U.S. at this time. A few words about each of these omissions is needed.

Health care, which is consuming over 14 percent of GNP (2.5 times as much as defense) is not primarily a technology program (except perhaps for the costs of using the technology in a wasteful manner). The biotechnology industry has been the beneficiary of the extraordinary investments in "pathbreaking" research by the U.S. government, even though the NIH research investments were not justified by an economic objective. Only recently has NIH taken its economic role seriously.

The environment does indeed pose important technical issues, both domestically and internationally, and, like health care, has a major economic impact, through cost burdens on industry and governments alike. This is an area of great importance to Brazil, and in which Brazil has taken a strong international leadership position, for example by hosting the UNCED.

Defense technology is dealt with extensively in this paper, but not from the perspective of defense requirements as much as from the considerable impact of defense procurement and R&D activities in the economy and the expectation that much of the new civilian technology program proposed by President-elect Clinton will be paid for out of defense funding. The defense establishments in the U.S. and in Brazil continue to have a major role in technology, but with the rising importance of economic goals, the role of defense is diminishing in both countries in comparison with private sector activity and government investments in industrially relevant technology.

Finally, this paper focuses on the health of universities because of their critical role in the S&T "food chain" and their contributions to technology diffusion. But it does not address the problems of education, either in the public schools or higher education, except in the context of the relationships of higher education to S&T and to the federal government. For a recent study of the federal government role in the reform of pre-college math and science education -- a major issue facing the U.S. -- see a recent study for the Carnegie Commission on Science, Technology and Government lead by the author: *In the National Interest: The Federal Government in the Reform of K-12 Math and*

Science Education, Sept. 1991, and other material cited in the Annotated Bibliography at the end of this paper.

The material in this paper was prepared by the author, but some sections have been taken from the author's unpublished work and from recent published work cited in the bibliography.

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1. Introduction

This review of U.S. science and technology policy and discussion of current issues is made at a time of rapid change in U.S. policy. The election of President Clinton and Vice President Gore brings a new generation to power in the U.S. federal government, the first persons elected to these offices since World War II who did not participate in that war. This is, perhaps, symbolic of a shift in American views of its role in the world. No longer are U.S. views colored by super-power competition with a nuclear-equipped and sometimes expansionist Soviet Union -- a view that affected American attitudes toward not only the USSR and its NATO allies, but unallied and development countries as well. The end of cold war, the rise of economic competition in an increasingly global economy, raid change in the nature and power of science and engineering, leave the U.S. with a new political, economic, and security agenda but with most of the same institutional structures in its government that were built up during the Cold War. In addition many Cold War era concepts about the nature of technological innovation and the part science and engineering play in it, still dominate political thinking.

Thus many of the concepts and new policy initiatives that have appeared in the late 1980s and early 1990s are transitional in nature, and may well change. This is also true of the missions of government agencies (especially Defense and Commerce), the roles of national institutions (government laboratories, universities, consortia of firms), and -- importantly -- the role of State governments in the promotion of economic activity through investments in technology, in industrial extension services, and in human resources. This paper will identify the post-war origins of U.S. S&T policy and the institutions that drive it, will analyze the elements of policy that are in flux, and will focus in its conclusion on the issues likely to be most hotly debated in the Clinton Administration's first year.

The boundaries that distinguish technology policy from economic and industrial policy are fuzzy at best. Technologies are created for economic reasons and the investments they call for must be economically justified. Technology is an important element of industrial success, but only one element, along with labor productivity, capital cost, and managerial skill. Technologies are almost never an end in themselves.[1] A technology is the aggregation of capabilities, facilities, skills, knowledge, and organization required to successfully create a useful service or product. Technology

[1] There are exceptions, perhaps, in the military sphere. Historians may conclude that the Strategic Defense Initiative of President Reagan, while never more than a technology -- and a highly speculative one at that -- had an important impact on Soviet perceptions of their ability to sustain the nuclear arms race, given the state of the Soviet economy. But the other example of a technology of enormous political consequence: the Apollo mission capability, illustrates that in the end only mission success counts.

policy concerns the public means for nurturing of those capabilities and optimizing their applications in the service of national goals and the public interest.

U.S. S&T policy is, with exceptions noted below, largely uncodified; it must be deduced by observation of the laws, the organization of government, and the actions of government managers and agencies. That policy is continuously in flux, and it is unclear what direction the *de facto* policy will take in the next decade. But certain generalizations about the directions of policy change can be made with some confidence:

* The Federal Government will gradually shift its priorities away from Defense and Space and toward technology development to support industrial competitiveness.

* Private firms, in a weakened anti-trust enforcement environment and responding to international competitive pressures and to changes in innovation processes, will move away from vertical integration in favor of alliances of many kinds with suppliers, distributors, and for pre-competitive and infrastructural R&D with competitors in consortia.

* Government decisions on civil technology activities will be increasingly shared with private sector bodies, and programs undertaken in evolving forms of public/private partnerships.

* Government technology policy will become increasingly well codified and will begin to shift from almost exclusive emphasis on generation of new technology to increased support for technology diffusion: accessing, adapting, and using technology.

* After a difficult and protracted period of down-sizing, the Defense effort (both procurement and R&D investment) will decline as a driving force in U.S. technology, and will move toward acquiring its increased fractions of its technology from commercial sources (foreign as well as domestic).

* The National Laboratories, which perform twice as much government funded R&D as universities, will find themselves with insufficiently compelling missions to sustain their current levels of effort, but efforts to re-mission or downsize them will be met with strong political opposition.

* The Universities will lose some of the autonomy they have enjoyed in research and will become more deeply engaged with creating "useful" knowledge and accelerating its diffusion to the private sector, but will continue to focus primarily on basic research open to all.

* State governments will become increasingly sophisticated in the services they provide to small and medium sized businesses to improve their productivity and to attract capital investment, and

the federal government will expand its encouragement to and cooperation with the States in this endeavor.

* International cooperation will increasingly influence American science, especially in its dependence on major facilities or foreign access, and basic technology development as governments begin to internationalize some of their civilian technology development activities to reduce trade frictions.

* It is increasingly anomalous that government, which is the source of finance for half the nation's R&D, insists on invoking three different and incompatible economic paradigms for technology generation, depending on the whether the purpose of the technology is to meet military, commercial, or environmental markets. Defense technology is generated in a command economy; economic competitiveness is left to a laissez-faire policy; and environmental technology is forced by regulatory pressures. The U.S. is moving toward a more integrated industrial technology base. That industrial base is increasingly integrated into the world-wide economy. That integration suggests that there will be a convergence of the policy tools for guiding technology in all three areas: military, commercial, and environmental.

The basic law that defines U.S. technology policy is the *National Science and Technology Policy, Organization, and Priorities Act of 1976*.[2] The occasion for this statute was the legislative establishment of the Office of Science and Technology Policy in the Executive Office of the President during the administration of President Ford. President Nixon had disestablished the predecessor Office of Science and Technology, which was a White House Office and not protected by statute. The 1976 Act for the first time documented the government's role in technology, and is often referenced in subsequent legislation about critical technologies or technological priorities. The Act gives some policy criteria for federal investments in technology for purposes other than established government missions:

> "It is further an appropriate Federal function to support scientific and technological efforts which are expected to provide results beneficial to the public but which the private sector may be unwilling to unable to support."[3]

> "Explicit criteria, including cost-benefit principles where practicable, should be developed to identify the kinds of applied research and technology programs that are appropriate for Federal funding support and to determine the extent of such support."[4]

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[2] 42 U.S.Code 6683.

[3] Section 6602, (b) (3).

[4] Section 6602 (c) (2).

The *de facto* U.S. technology policy is, indeed, shifting rapidly from its emphasis on development of technologies to serve missions assigned to the federal government, particularly in the defense, space, and nuclear fields, to programs intended to enhance the economic performance of private industry. The general directions of policy evolution where laid out by Dr. D. Allan Bromley in 1990 in the first formal declaration of Technology Policy by the Bush Administration.[5] The year before, President Bush had publicly declared his intention to provide cost-shared support for "precompetitive, generic" technologies of value to commercial industry, as indeed the Congress had authorized in the 1988 Omnibus Trade and Competitiveness Act.

During 1992, perhaps in response to the upcoming Presidential election, the Bush Administration substantially accelerated its initiatives in technology support to the economy even as its political rhetoric continued to warn against industrial policy. It requested growth in the Advanced Technology Program in the Department of Commerce to $ 69 million for Fiscal Year 1993. It announced new R&D initiatives in High Performance Computing and Communications, Advanced Materials and Processing, and in the non-defense component of manufacturing research and development. It continued its investments in the National Research and Education Network."[6] A substantial acceleration of policy change can be anticipated under President Clinton if the incoming administration implements the strategy described in the September 21, 1992, statement of the Clinton-Gore presidential campaign organization[7] and a related statement of manufacturing strategy. These policies (together with others addressing national security, environment and health) represent an acceleration of ideas for federal activity in support of industrial competitiveness that differ from initiatives already taken by the Bush Administration and the Congress primarily in their pace, scale, and the level of confidence in their effectiveness.[8] Nevertheless, there is still a weak consensus on

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[5] D. Allan Bromley, *The U.S. Technology Policy*, (Washington DC: The Executive Office of the President) Sept. 26, 1990.

[6] L. M. Branscomb, "Technology Policy and Economic Competitiveness" in *Science and Technology Policy Yearbook 1992*, (Washington DC: American Association for the Advancement of Science) 1992.

[7] *Technology: The Engine of Economic Growth*, Clinton-Gore campaign document issued Sept 21 1992.

[8] The elements of policy include: (a) support for R&D in support of the commercial industrial base (a civilian DARPA is mentioned, but the program seems similar to ATP in Commerce); (b) an aggressive program to build 172 manufacturing extension centers, building on the current NIST MTCs; (c) investment in information infrastructure (an extension of the current NREN program to schools, libraries and hospitals); (d) a focus on human resource development -- with one welcome addition to current federal activities: an apprenticeship program on the European model to address school to work transition for the non-college bound.

the appropriate roles for government funding of science and technology in support of economic performance.

Indeed, it is unclear how enthusiastic the Clinton Administration will be for technology investments as a tool for economic revitalization. Despite many strong statements on the campaign trail, the transition period after the election saw great prominence give to the "economic team" of senior officials in the new administration, but the President's Advisor on Science and Technology -- a position ranked with the Director of the National Security Council -- was not among them. The nomination of Dr. John Gibbons (the director of the Congressional Office of Technology Assessment) to this post was made with virtually no fanfare or media attention, quite surprising in view of the prominence given to the appointments of others to this office and the central role science and technology are said to have to the economy.

2. Postwar Science and technology policies[9]

During the four decades after the Second World War, the United States attained the highest level of scientific and technological achievement in history. With the world's largest economy and the strongest armed forces, it helped to defend the cause of free society. It did so with outstanding success. New industries with revenues of hundreds of billions of dollars were created from scratch after the war, born from the creative powers of American science and engineering. As by-products of investments for defense, the aviation, computer, and microelectronics industries became leaders throughout the world. American universities attracted the interest and admiration of all countries, and they still attract one third of all the students in the world who study abroad. In only five years, Americans created the organization, the facilities, and the technology for manned exploration of the surface of the moon.

[9] For an historical analysis of post war U.S. science policy, see Bruce Smith, *American Science Policy Since World War II,* (Washington DC: The Brookings Institution) April 1990. For an analysis of U.S. technology policy, with emphasis on national security and economic concerns, see Alic, John, Lewis M. Branscomb, Harvey Brooks, Ashton Carter and Gerald Epstein, *Beyond Spinoff: Military and Commercial Technologies in a Changing World*, Harvard Business School Press, 1992. For an annual summary of issues, documents, and data about U.S. science and technology policy, see Margaret O. Meredith, Stephen D. Nelson, and Albert H. Teich, eds., *Science and Technology Policy Yearbook 1991 (and annually)*, Washington DC: American Association for the Advancement of Science, 1991 (and annually). Other recommended references will be found in the Annotated Bibliography at the end of this paper.

The policies under which these achievements occurred were clearly articulated in Vannevar Bush's report to President Truman, entitled *Science the Endless Frontier*.[10] The period from the early 1950s to about 1968, when the growth of American science came to a halt for ten years, is often called the "golden age of American science." It was the best of times for scientists in American history.[11]

The essence of the post-war policy for science and technology had two parts: (a) governmental support for research in basic science and (b) active development of advanced technology by federal agencies in pursuit of their statutory missions.[12] Dr. Henry Ergas characterizes this policy, like that of Britain and France, as "mission-oriented" technology policy.[13] He contrasts this approach with the "diffusion-oriented" policies of Germany, Switzerland, and Sweden, which is an alternative approach to national technological development.

Thus five assumptions have characterized U.S. S&T policy since World War II:

> (a) Basic scientific research is a public good. Investment in it, especially in combination with higher education, leads, through a sequential process of innovation to the creation of new technologies which in turn may spawn new industries.
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> (b) In fulfillment of the Government's responsibilities for defense, space exploration, and other statutory responsibilities, federal agencies should aggressively pursue the development of new technology for use in these missions. The technological fruits of such a mission-driven, high tech strategy will automatically and without cost to the government "spinoff" to commercial uses, thus further stimulating industrial innovation.
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> (c) By refraining from direct investments in research to create technology specifically for commercial exploitation, and leaving to private industry the responsibility for tapping into these two sources of science and technology support, the reliance on market forces to stimulate industrial competitiveness is not compromised.

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[10] Bush, Vannevar, *Science, the Endless Frontier*, Washington DC: National Science Foundation, pp 5-40, July 1945, reprinted 1960, 1980, and in 1990.

[11] It was not the best of times from a civil liberties point of view, for this is when Senator Joe McCarthy was challenging the patriotism of many scientists.

[12] Smith, Bruce L. R., *American Science Policy Since World War II*, (Washington DC: Brookings Institution, 1990, pp 48-52, and 164-166.

[13] Ergas, Henry, "Does Technology Policy Matter?" in Guile, Bruce R. and Brooks, Harvey, *Technology and Global Industry: Companies and Nations in the World Economy*, (Washington, D.C.: National Academy Press, 1987). p. 192.

(d) Complementing the centrally-directed, publicly-financed strategy for developing military technologies and the laissez-faire strategy for developing commercial technology, a third strategy for environmentally useful technology has relied on the use of regulation to force private investment -- a strategy based on the idea that environmental costs have only a negative impact on the economy, which fails to reflect a huge future world market in environmentally useful technologies.

(e) U.S. science and the economy have been sufficiently strong that government viewed science and technology as assets to be deployed internationally in support of political goals and building alliances to contain the Soviet Union. Technologies such as rockets, nuclear fusion and fission, and surveillance from space were deployed in the interests of free world security; the "peaceful uses of atomic energy" program, the civilian exploration of space and the Landsat program were designed to make these military-driven technologies more acceptable to publics at home and abroad.

Each of these elements of American policy after the Second World War entailed a tacit assumption about the mechanism through which government investments in research and development would contribute to industrial innovation, and hence to the competitiveness of American products in the world market. These two assumptions are derived from a "supply-side" picture of how the process of innovation works industry based on high technology.

Governmental support of basic research is justified, economists say, because the social returns from basic research exceed its cost, but the private returns to a firm investing in basic science are less than its costs because of low appropriability of the benefits. Professor Edwin Mansfield's analysis of all the evidence suggests that the social return from basic science in the United States in the late 1980s was about 28 percent.[14]

a. "Pipeline" and "Spinoff": Images of the Contribution of Science to Technology

The bi-partisan support for science in the United States Congress has rested heavily on the acceptance of the "pipeline" model of the process by which that social return arises in the form of industrial innovations.[15] This conventional, but now discredited, model assumes that innovations arise in the

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[14] Mansfield, Edwin, "Academic Research and Industrial Innovation," *Research Policy*, vol. XX, (1991), pp. 1-12.

[15] Kline, Stephen, "Models of Innovation and their Policy Consequences," in Inose, H., Kawasaki, M., and Kodama, F., eds., *Science and Technology Policy Research: "What should be done? What can be done?"* (Tokyo: Mita Press, 1991), pp. 125-140. For background, see Kline, S., and Rosenberg, N., "An Overview of Innovation," in Landau, Ralph, and Rosenberg, Nathan, (eds.),

research laboratory or the inventor's shop, and are produced after a sequence of steps through applied research, development, design, and production. It is further assumed that this process is more or less automatic and inevitable, in which case a science policy oriented to basic research is, in effect, a necessary element of a successful technology policy and assumes a prosperous economy.

The "pipeline" model is not a bad description of how new industries arise from new science -- a process that takes a decade or more. The model served the United States well during the post-war period of reconstruction when it had no serious competition from overseas in the field of advanced technology. The emerging bio-technology industry owes its origins primarily to the research in the science of molecular biology, genetics, and biomedical science funded by the National Institutes of Health. In the last decade NIH has invested over $ 60 billion in research conducted in the NIH institutes and in universities funded by NIH. The pipeline model is, however, inapplicable to the way established industries compete through rapid incremental progress.[16] The "pipeline" model is an even less appropriate description of how firms in high-technology compete in the 1990s.

The second arm of American post-war policy has expressed faith that the technology created in pursuit of governmental missions will automatically flow to industry and will make for a prosperity. The process through which this is presumed to happen is called "spinoff."[17] A key reason for its appeal is that "spinoff", like the "pipeline" from basic science to innovation, is assumed to be automatic and cost-free. Both of these assumptions, drawn from "supply-side" economic ideas, have the attractive feature that *if* they are automatic and cost-free the government does not have to "pick winners and losers" in order for the economy to gain the benefits. Government can then claim that its policies achieve the goals of economic growth without interference with the autonomy of private firms.

While "spin-off" has, in fact, never been either automatic or cost-free, there are examples of commercial products "spun-off" from military developments. A classic case is the Raytheon Corporation's microwave oven, the trade name of which, the Radarange, discloses its military origin. Most cases of successful "spinoff" occurred soon after the Second World War, when military research and development in the United States dominated commercial research and development. Even as late as 1960, American expenditures for military research and development were a third of all the

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Positive Sum Strategy: Harnessing Technology for Economic Growth, (Washington DC: National Academy Press, 1986.) pp. 275-306.

[16] Gomory, Ralph, "From the Ladder of Science' to the Product Development Cycle," *Harvard Business Review,* Nov.-Dec. 1989, pp. 99-105.

[17] Alic, J., Branscomb, L.M., Brooks, H., Carter, A., and Epstein, G., *Beyond Spinoff: Military and Commercial Technologies in a Changing World*, (Boston: Harvard Business School Press) May 1992.

expenditures for research and development, public and private, by all the member-countries of the Organization for Economic Cooperation and Development put together. Today it is only one seventh, and is predicted to be more like one tenth by the year 2000.

As a further guarantee against central political control over scientific and engineering activities, American policy after the war called for a highly decentralized responsibility for investing in research and development by federal agencies. Under principles advanced by Vannevar Bush but executed following the Steelman Report[18] a few years later, all federal agencies were to develop the technology needed for their assigned tasks and were also to support a proportionate share of the country's basic research as a kind of "mission overhead" re-investment in the basic knowledge on which their technology depended. Furthermore the autonomy of academic science was to be preserved by competitive selection, by peer review, from unsolicited proposals.

b. Dominance of Defense R&D

World War II, and the cold war that followed, dominated government S&T strategy in the post-war period and gave it its "supply side" or "mission-oriented" character. In 1960 U.S. defense R&D comprised a third of all the R&D, public and private, performed in all the OECD countries.[19] U.S. military R&D was, in effect, the sole engine in the non-communist world for technological development of the emerging "high-tech" industries. Military procurement and government-funded R&D were big factors in the early post-war development of the U.S. electronics, computer, and aircraft industries.[20] If the process of diffusion of military technology to commercial firms was slow, no foreign firms were seriously challenging the U.S. industrial lead in these markets. American universities were prolific sources of new science from which technologies evolved. In contrast with today's environment of Congressional distrust and confrontation in defense acquisition, defense agencies in the 1950's and 1960's took technical risks and enjoyed a healthier partnership with their contractors. Much of the stimulation given by defense to technology came through adventurous procurement, not through funding of R&D. A massive national science and technology enterprise was built, with many institutional innovations.

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[18] President's Scientific Research Board, *Science and Public Policy: Administration for Research*, 3 vols., (U.S. Government Printing Office, 1947), vol. 1, page 26, usually referred to as the "Steelman Report." These recommendations were ordered to be carried out by President Eisenhower in Executive Order 10521, 17 March 1954.

[19] *Beyond Spinoff, loc. cit.* p.

[20] In 1960 government expenditures on R&D dominated private investments ($ 8.7 B to $ 4.5 B). In that year 80 % of federal R&D investments were from Defense. In 1963, if you include Atomic Energy and Space with Defense, they comprised 93% of the federally supported R&D effort and more than 2/3 of the entire national effort, public and private. In effect, it was the national effort.

Those institutions and relationships shaped the policies we inherit today. Unfortunately they remain rigid and resistant to change. A system of national laboratories emerged to support cold-war technology needs. Today these government-funded laboratories enjoy a major share of federal research dollars, ($ 20.8 billions in 1992). However they face uncertain missions and weak relationships with the private commercial sector (see IV.C.3). Industry finds itself divided into two weakly coupled economies -- one of defense firms, the other serving civilian markets. Although most of the large prime contractors are subsidiaries of much larger commercial organizations, the barriers between military and commercial units effectively prevent the sharing of technology between them (see Fig. 1).

Figure 1:
Two Cultures: Civil and Military Innovation

Attribute	Civil	Military
Design driver	Driven by markets	Driven by "requirements"
Innovation style	Incremental	"Big leaps"
R&D Intensity	Moderate	High: 4.9 times civil firms
Product cycle	Measured in years	Measured in decades
Techn. Priorities	Process technology	Product technology
Busin. Priorities	Low cost, high quality	High performance
Production rates	High rates and volumes	Low rates and volumes
Linkage of R&D with Production	Integrated R&D, manufacturing, and service	R&D separately contracted and managed
Technology sharing	Success based on proprietary advantage	Government may require sharing with second source

In short, the U.S. manufacturing economy has two cultures, one military, the other civilian. Government R&D institutions reflect the military culture rather than the civil one. The resulting government activities are out of touch with the fleet-footed, low cost, high quality manufacturing so vital to manufacturers of commercial products.

c. The Social Contract with Science

Throughout the Post-War period, an implicit social contract between scientists and the government balanced the government's commitment to respect scientific autonomy with an undertaking by the scientific community that scientific excellence would contribute to national well-being. Society would allow scientists to administer the competition for funds and to exercise an honest stewardship of those funds, so long as excellence in science was sustained. This social contract enjoyed bi-partisan support in the United States Congress and was essentially unchallenged for four decades. Despite the Mansfield Amendment, which required the Department of Defense to support academic research only if it was clearly relevant to military matters, and despite the program called Research Applied to National Needs (RANN) of the National Science Foundation, the willingness of the federal government to support basic research was very well maintained.

In short, the American policy after the Second World War and its "pipeline" and "spinoff" images, sought to avoid affronting the businessmen's abhorrence of industrial policy and the scientists' abhorrence of centrally planned science, while still retaining the benefits of technological stimulation of the economy. The political attractiveness of this policy helps explain its persistence, despite the fact that its assumptions are no longer realistic today.

Today both the social contract between scientists and government and its assumptions are seriously challenged. Although the Congress and the Administration have, in the main, resisted demands for the reduction of governmental appropriations for scientific research, there are warning signs that the long-prevailing social contract has ceased to be adequate. Some of the difficulties concern the political standing of scientists and their institutions.

The scientific community no longer enjoys the unqualified respect of political leaders that it had some years ago. In January, 1992, the president-elect of the American Association for the Advancement of Science, Professor Leon Lederman, a Nobel laureate in physics, warned that inadequate federal support for basic scientific research seriously threatened American science.[21] His cry of alarm was regarded by many politicians as a cry of "wolf!" Many of them treated Lederman's warning as both self-serving and politically naive, having regard to the large demand for domestic welfare expenditures and concerns about the insufficient competitiveness of the American economy in the world market.

The prestige of universities is declining as well. Allegations of scientific misconduct in federally supported research, criticisms of the accounting practices of the universities in the calculation of overhead costs on government grants for research, dissatisfaction with solicitations of funds from foreign corporations by academic scientists in return for giving them preferred access to the results of governmentally supported research have fostered a cynical attitude towards the universities in the United States.

The social contract provided that the allocation of federal research funds would be made on the basis of the scientific merit of proposals as determined by peer review. This is now breaking down. With too many investigators competing for too little money, the United States Congress is becoming increasingly impatient with the concentration of awards in the most distinguished universities. Ignoring the long-standing affirmation that grants would be awarded on the basis of merit, Congressional committees each year divert an ever larger percentage of funds for research and development to favored applicants, through "riders" on legislative proposals, referred to as "earmarking". This is the principle of the "pork-barrel", not the principle of merit, and the total funding for academic facilities and related expenditures has grown at a 30 percent compounded rate since 1988, reaching an estimated $ 1.3 billion in FY 1993.

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[21] Lederman, Leon M., *Science: The End of the Frontier?*, A report from the President-elect to the Board of Directors of the American Association for the Advancement of Science, January, 1991.

The situation was depicted by the President's assistant for science and technology, Dr. Allan Bromley, who said -- only partly in jest -- in May, 1991, that "It used to be that if you probed someone in the universities about their views of Congress, they would often accuse Congress of being a bunch of crooks. Now if you probe someone in Congress about the universities, Congressmen will frequently claim that the universities are full of crooks."[22]

A fourth source of pressure on the social contract between scientists and government arises from growing recognition that "supply-side" reliance on the "pipeline", on "spinoff", and on the decentralized allocation of resources no longer meets the economic and social needs of the United States. This has led to a call in the Congress for a rethinking of United States science and technology policy. Frustrated by the apparent failure of America's world leadership in science to assure the international competitiveness of United States high-technology industry, the Congress is turning its attention from academic science to lists of critical technologies (see IV.A.). It presses the Administration to support "pre-competitive, generic" technology which will be of direct interest to private industrial firms (IV.B).[23] In Washington today one hears much more discussion about technology, much less of scientific research. The "pipeline" and "spinoff" metaphors are fast losing their plausibility, as politicians and the executive branch search for a politically acceptable, economically effective, more "demand-oriented" approach to strengthening the base of American technology.

The stability of the relationship between universities and the federal government is now in question. How it is resolved -- what the terms of a new social contract might be -- will be one of the major S&T policy issues evolving in the next few years.

d. Four sources of change

Americans now understand that the world has radically changed. But the paradigms on which the post-war S&T policy consensus rests are still firmly planted in many people's heads, especially in Washington, and the institutions of government that will be needed to implement a new consensus

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[22] Bromley, D. Allan, "Science and Technology Policy: An Agenda for the Future," George Washington University Science and Technology Policy Seminar, 7 May 1991 (unpublished).

[23] *Gaining New Ground: Technology Priorities for America's Future*, (Washington DC: Council on Competitiveness), March 1991. *Report of the National Critical Technologies Panel*, (Washington DC: U. S. Government Printing Office), March 1991. President's Council on Competitiveness, *Achieving Competitiveness in National Critical Technologies: Policies in Support of Technology Development in America*, (undated: about April 1991) office of the Vice President, 8 pages.

have changed hardly at all. But three major changes in the U.S. will require not only a rethinking of technology policy, but changes in institutions and new international linkages as well:

(a) Recognition that defense priorities will no longer dominate the U.S. federal government's technology policy. Instead defense must face a drastically shrunken production and weapons acquisition base, will have to increase the fraction of the defense budget devoted to exploratory development and prototyping, even as the defense R&D budget decreases. Because the technologies critical to the new force structure will increasingly fall into areas in which commercial industry is ahead of defense industry, especially the information and communications technologies, defense agencies will have to gain access to commercial technologies. This will require radical change in defense acquisition policies and practices.

(b) Recognition that progress in modern, science-based engineering depends increasingly on a publicly-provided infrastructure of basic technical knowledge, tools, materials, and facilities. Between the realms of basic science and proprietary technology there lies a large domain of public good technology, whose value in application is clear but in which firms under-invest because of low appropriability of the benefits. Much of this "infrastructural technology" supports the creation and improvement of design and process technologies. Such capabilities concurrently support military, commercial, and environmental goals. But reliance on "spinoff" from mission-oriented government R&D, on generation by hard pressed private investors, and on technology-forcing through administrative and tort law does not provide the nation with the long term capability to remain both a technological and economic leader. In short, we need a publicly supported technology base, supporting industry's capability to create technologies for all three areas of national need.

(c) Recognition that economic performance in a competitive world economy rests primarily on how well the society uses the existing base of technology, skills, and scientific understanding, and only secondarily, and accumulated over time, on annual additions to this stock of capability. It follows, then, that the government's technology policy must give much greater emphasis to the diffusion of technical knowledge and skills. The primary elements of a diffusion strategy are: aggregating, evaluating, communicating, and absorbing non-proprietary information. The primary mechanisms are through education, mobility of technical personnel, and networks (both facilities and institutions) for promoting cooperation and sharing. The states, as well as federal agencies, have major responsibilities here, especially for industrial extension services.[24]

i. End of the Cold War

The revision of defense strategy is driven by a change in requirements and the necessity of meeting them with significantly reduced investment. World events suggest that the risk of either strategic nuclear confrontation or large-scale conventional war with the Soviet Union are rapidly receding. However, the danger of regional conflict with unexpected spill-overs has not abated. The outbreak of old ethnic and nationalistic tensions suggests that this risk may even increase. Furthermore the range and destructive potential of weapons increasingly available to third world countries increases the danger of terrorism and regional conflict. New priorities in defense will be called for:

* Command, control, communications and intelligence (C^3I) will continue to be of the highest importance, both for regional conflict and for arms control compliance.

* Mobility of forces, smart weapons for pin-point targets, ability to limit collateral damage, capability to deal with individual and state terrorism, all seem to be priorities.

These capabilities, particularly those concerning C^3I and logistics, are strongly rooted in "dual use" technology. All of them require a strong base of science and of generic "building-block" or enabling technologies. As the Defense Department restructures its force structure, a technology strategy should be developed to sustain it. This strategy should include explicit provision for

(a) A system for establishing military requirements that takes the capabilities of commercial as well as defense industry as the starting point, to achieve the most cost effective compromise between optimal functionality and minimum cost;

(b) The development of selected prototypes for field testing since fewer new weapon systems will be produced, and higher confidence in their estimated costs and functionality is needed before commitment to production;

(c) Expanded fundamental research (6.1) and exploratory development (6.2) to broaden the inventory of technical knowledge and increase the spectrum of technical choice, including

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[24] Shapira, Philip, *Modernizing Manufacturing: New Policies to Build Industrial Extension Services,* (Washington DC: Economic Policy Institute, 1990).

more emphasis on process technology essential for minimizing production costs and maximizing quality;

(d) Changes in the defense acquisition system that will encourage commercial firms to sell to the military without compromising their proprietary interests and will give defense agencies effective access to the best commercial technology.

Such a policy would serve both defense needs and the needs of the industrial sector. It will increase the ability of the civil sector to support future defense needs, particularly in design, production and quality - the primary focus of competitiveness concerns. It is a policy that makes sense whether or not the civil agencies -- Commerce, Energy or NSF, for example -- are charged with investing in the nation's technological comparative advantage. Putting such a policy into effect faces very serious political obstacles; few are sanguine that it will be successful any time soon.

ii.Rise of Economic Competition

It should come as no surprise that the images of innovation on which U.S. technology policy has been based should be re-examined. The United States is in a different world from the one it inherited after the Second World War. There is no reason to believe that policies that worked so well in the 1950s and 1960s will work well today. A multi-polar world is emerging in which international economic competitiveness and environmental health are replacing military strength as the most urgent objectives of national and world-wide security.

The economic integration of Europe is expected to take a great stride forward in 1993. Its integrated market will be both opportunity and a competitive challenge for American firms. The emerging countries of Eastern Europe are attempting to reorganize their economies to give a central position to the free market. In those countries, virtually every aspect of the way in which industrial innovations occur, technology is diffused, and producers collaborate and compete must be learned and institutions created to support them. The United States economy will be challenged to help them succeed, and to make the investments that may allow Americans to benefit in the future from the economic success of the new states which replace the communist regimes of the USSR and eastern Europe.

Many of the economies of nations in Asia, Latin America, and Africa are also under stress, and the industrial democracies can no longer ignore their plight. There is growing awareness that the world cannot achieve a stable physical environment, or beneficial international trade, unless the needs of the developing countries are taken into account. New policies through which the developing countries can acquire technologies to support their development in a more environmentally sustainable way will be required.

At the same time there has been a great shift of economic production to rapidly industrializing nations in South America and Asia, where Japan has joined the leaders of the world economy. Forty percent of the gross national product of the entire earth is now produced in the United States and Japan, with the Japanese share increasing.

Economists argue about whether the economy of the United States is suffering from long-term structural weakness or whether it is only experiencing the transient strain of structural dislocation in a very active world economy. Nevertheless, the pronounced diminution of the American share of world markets in machine tools, semi-conductors, telecommunications and office equipment forces us to ask: Why has the comparative advantage of the American economy declined so sharply in these science-intensive industries in spite of American achievements in science and technology?

The short answer is that American firms, and the government of the United States, have been much too slow to recognize the power of modern science and engineering to transform the way products are designed and produced. They have also been slow to take advantage of new forms of industrial organization and management through which technology is used to reduce costs, increase quality, and accelerate responses to market forces.

iii. Changes in Science, Engineering, and Innovation

New ideas are now required in many areas of modern industry. The ideas on which we used to draw in thinking about industrial innovation are no longer adequate. Japan has been a particularly fertile source of these new concepts, many of which are expounded by Prof. Fumio Kodama in a book which was awarded the Yashino Sakuzo prize in 1991.[25] These new ideas have rendered traditional concepts of product development and mass production out of date; they are now being adopted on a world wide scale.

The new conceptions of industrial innovation focus on the process of production; they do not take research and development as points of departure. They must be described by a model of innovation which envisages mutual interactions between design, production, marketing and research, not by a sequential "pipeline" of activities starting with research, ending with marketing. These new approaches to innovation have changed the level of performance required for being competitive in world markets. Some examples include the use of computer-integrated manufacturing using "intelligent tools" to break the connection between economies of scale in production and the lot size of similar parts.

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[25] Kodama, Fumio, *Analyzing Japanese High Technologies: the Techno-paradigm Shift*, (London: Pinter Press) 1991.

Quality is increasingly controlled through the accurate characterization and precise control of industrial processes, rather than by testing after production is completed. Processes and systems of production (rather than research and product development) are becoming primary elements of the strategy for achieving products of low cost and high quality. Incremental improvements in products are being made by manufacturing and process engineers rather than by specialists in design and in research and development. This is a radical departure from the traditional process of sequential development and production.

Various forms of alliances and relationships of industrial firms are being used as alternatives to vertical integration as means of gaining the benefits of technological specialization. Technological diversification is being used by established firms to guard against competition from enterprises experienced in technologies unfamiliar to the particular industry of the established firms.

"Trickle-up technology" is another Japanese innovation. Japanese electronics firms introduced new technologies, such as liquid crystal displays and low-power CMOS integrated circuits, in wrist watches and other consumer products, while most American companies derive new technologies from their most sophisticated business products, such as main-frame computers. The American approach has the advantage that expensive business products can generate high revenues to pay for the development of the technology, and the first implementations of it in products can tolerate high initial costs. With experience, these costs are reduced and the technology will appear in higher volume, lower cost products, such as those consumers buy. The Japanese "trickle up" strategy, on the other hand, gives the firm much earlier experience with high volume manufacturing of the technology. By keeping the initial performance requirements modest, this early manufacturing learning gives these firms a very low cost production capability, which can then be used to enter markets for more expensive business products with a substantial cost advantage. These new approaches to industrial activity and others like them have many consequences.

While most of these new approaches emerged in "high-technology" industries, we now understand that the right criteria of "high-technology" is not complexity of the product or novelty of its function, but is the choice of the pattern of production that makes the most intelligent use of materials, energy, and human resources. Any business can and should make use of the best practices from high technology. Firms using high technology are rapidly shifting from primary dependence on capital and labor resources to dependence on research and development as the primary resource for remaining competitive. In Japanese high-technology firms in 1991, investments in research and development exceeded the firm's annual investments of capital in production equipment and facilities, a shift made possible by the flexibility of computer-integrated manufacturing systems.

iv. Weakened Control by National Governments

National governments will have steadily decreasing ability to unilaterally control flows of money, people, technology, and business alliances across national borders. Governments looking for quicker response of their economies to opportunities and challenges in world markets will continue to privatize their own activities, to look to public-private partnerships for achieving public goals, and to international negotiation and collaboration to sustain both economic and political relationships. Furthermore, in consequence of the accelerated mobility of capital, technology, and individuals, and the steady reduction of barriers to trade, national boundaries are rapidly losing their significance as delineating the territories within which innovations are generated and applied. One consequence of these developments is the diminished capacity of any government to control technological movements within and across its own boundaries. It is not feasible to establish and maintain for extended periods a monopoly on any technological innovation.

e. New policy directions

As the rates of diffusion of innovations accelerate internationally, transnational firms can more easily initiate production in many geographical locations simultaneously. The rates of diffusion of technology within a national economy must become even more rapid if firms of that country are to have a competitive advantage in the international market. The acceleration of technological diffusion must become a major objective of policies for enhancing the economic position of the country internationally. Technology also diffuses much more rapidly as technical knowledge becomes codified. Knowledge gained from learning through experience, on the other hand, is much more difficult to transfer and diffuses through apprenticeship and collaboration at a much slower rate.

Where the increase of economic competitiveness of a firm, an industry, or a country is the object of policy, it is important that the new approaches to innovation foster a drastic reduction in time between the detection of potential market demand and its satisfaction through production in large quantities, thus enhancing satisfaction of consumers and dramatically reducing the cost of product and market innovations. Thus the two main arms of policy debate are:

> * Supply-side policy: Under what circumstances and through what mechanisms should government make investments in science and technology in support of national objectives, especially economic objectives?
>
> * Demand-side policy: What investments in knowledge infrastructure, in technology access, adaptation, and absorption should governments make, and how can the infrastructure and technical services be made efficient and responsive?

3. U.S. Science and Technology: Data and Trends

a. U.S. R&D in Relation to GDP; Comparative Analysis

The United States federal government operates over 750 major research institutions and has under contract a great many more. Some 380,000 scientists and engineers work in 3000 R&D centers, laboratories, experiment stations, and related research agencies and bureaus.[26] Total U.S. expenditures on research and development totaled some $ 130 billions in 1987, larger than the R&D budgets of Japan, Germany, France, England, Italy and Canada in total. Comparing each government's R&D expenditures, the U.S. government spent, in 1987, 60 percent more than all those other governments combined.[27] Yet more than 30 percent of U.S. R&D is devoted to defense related activity, four times higher than that of the other large R&D spenders in the OECD.

[26] U.S. Bureau of Labor Statistics, *Monthly Labor Review*, Sept. 1987, and Kay Gil, ed. *Government Research Directory* (Detroit: Gale Research, 1985), quoted in James E. Katz, "Mechanisms for Providing Science Advice to Congress," Draft paper for the Carnegie Commission on Science, Technology and Government, unpublished, 9/21/90.

[27] OECD, *Main Science and Technology Indicators*, 1990-1 (Paris: Organization for Economic Co-operation and Development, 1990) page 16, table 2 and page 20, table 14.

Table 1

National R&d Comparisons - 1988 [28]
(U.S. $ billions -- OECD purchasing power parities)

Country	R&D Spending	Defense R&D	R&D/GDP (percent)	Nondefense R&D/GDP
U.S.A.	133.7	43.0	2.7	1.9
Japan	47.0	0.4	2.6	2.6
F.R.G.	24.6	1.1	2.8	2.7
France	17.5	3.9	2.3	1.8
U. K.	17.0	3.3	2.2	1.8
Italy	9.1	0.6	1.2	1.1
Canada	6.4	0.3	1.4	1.3
Netherlands	4.3	0.1	2.3	2.2
Sweden	3.6	0.4	2.9	2.6
Switzerl'd	3.2	0.1	2.9	2.9
Total non-U.S.A.	$132.9	$10.2	2.3	2.1

[28] From Table 4-1, page 89, in *Beyond Spinoff, loc.cit.* See footnotes to table in the reference for sources and interpretation.

The U.S. spends approximately the same fraction of Gross Domestic Product on R&D as do our main high tech industrial competitors (Japan and Germany) (see Fig. 1). In 1990 this was 2.7 % for the U.S., 2.6 % for Japan, and 2.8 % for Germany. But the **non**-defense component of this R&D represents only 1.9 % of GDP for the U.S., and 2.6 and 2.7 % of GDP for Japan and Germany.[29] The difference is 0.7 % of GDP or $ 43 Billions -- the level of Defense R&D spending in 1990.[30] Assuming that all three countries are equally efficient in using R&D, one is drawn to one of two hypotheses:

a) U.S. defense R&D is at least as effective as civil R&D in stimulating economic performance.
If so, it must be possible to find some $ 40 Billions in spinoff to private firms from national laboratory research -- a conclusion the authors of *Beyond Spinoff* cannot support for the economy as a whole.[31]

b) Defense R&D is significantly less effective than civil R&D in promoting economic performance.
If so, U.S. industry competes with a national R&D shortfall of $ 43 billions. This argument motivates many to conclude that the U.S. must find a way to shift the R&D capacity, and the funds that support it, from current programs in defense and nuclear weapons labs to private industry, or -- at minimum -- to the government's civilian programs more helpful to industrial competitiveness.

Such a shift, referred to as "defense conversion" is a daunting political task, but it is the argument that motivates much of the Clinton-Gore technology policy.

b. Sources and performers of U.S. R&D Investment

Table 2 shows the sources of R&D funding in the U.S. and the R&D performers who spend it. Note that approximately half the U.S. R&D total of $ 145 billion in 1990 comes from government, and half from private industry. But much of the government's investment is spent in private industry, so industry performs almost three quarters of the R&D in the U.S.

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[29] J. Alic, L. Branscomb, H. Brooks, A. Carter, and G. Epstein, *Beyond Spinoff: Military and Civilian Technologies in a Changing World* (Boston: Harvard Business School Press, 1992). Table 4-1, page 89.

[30] ibid. Table 4-1, page 89.

[31] See *Beyond Spinoff,* chapter 6. Defense R&D is concentrated heavily in aerospace and electronics. In some industries, jet engines and communications satellites, for example, defense R&D and procurement do have a clear stimulating effect on commercial technology. In others, such as computers, the technology flows the other way ("spin-on").

The universities perform only 14 percent of national R&D, and a disproportionate fraction of the basic research. It is also notable that the federal agencies

Table 2
1990 U.S. R&D Funding: Sources and Performers[32]
$ Billions

Funding Sources [read down]	Performer Federal Labs	Institution Univ. run FFRDC's	[read Industry	across] Univer-sities	TOTAL	Percent Funded
U.S. Govt	$ 16.1	$ 4.8	$ 31.3	$ 11.8	$ 64.0	44.0%
Industry			72.9	1.8	74.7	51.4%
University				6.8	6.8	4.6%
Total($B)	$ 16.1	$ 4.8	$ 104.2	$ 20.4	$ 145.5	100 %
Percent Performed	11.1%	3.3%	71.6%	14.0%	100%	

[32] Table 4.2 from *Beyond Spinoff, loc. cit.*, page 92. See footnotes on this table for sources. FFRDCs are Federally Funded Research and Development Centers; the largest of them are national laboratories of the Department of Energy and NASA.

fund only half of the university research; much of the rest is self funded (although much of that comes from state governments to their state-run universities). The federal and national (FFRDC) laboratories, taken together outperform the universities ($ 20.9 billion to $ 20.4 billion), with more than twice as many federal dollars, a situation now drawing criticism in the post cold war period. Within the FFRDC category are some huge technical enterprises devoted to nuclear weapons technology. Three of the Department of Energy's government-owned, contractor operated laboratories, the Los Alamos Scientific Laboratory and the Sandia laboratory in New Mexico and the Livermore Laboratory in California, have combined R&D budgets exceeding $ 3 billion in total. With the signing of the Start II Treaty, there will be substantial excess capacity in these laboratories -- the subject of discussion in section 4.c.iii.

Although the budgets of both defense and the Department of Energy National Defense Program (nuclear weapons) are in decline, they are very much larger, even in their shrunken state, than the R&D budgets of the civilian agencies. It is important to remember, as one discusses policy alternatives for new investments in the commercial technology base, or in knowledge infrastructure, that the current budgets for these activities are tiny by comparison to those of traditional defense, space, and energy programs. See Table 3. It will take a long time for the Congress to get sufficient confidence in the new technology policy initiatives to bring their funding up to levels at all comparable with more traditional federal missions.

Table 3

Allocation Federal R&D spending by subject, 1992.[33]

Millions of Dollars

Federal R&D Budget Function	$ millions
National Defense	$ 43,247
Health Research	9,649
Space Research and Technology	7,656
General Science	2,962
Energy	2,920
Natural Resources and Environment	1,602
Transportation	1,380
Agriculture	1,091
Education, training, employment, social services	510
International Affairs	413
Veterans services	219
Commerce and housing credit	200
Community and Regional development	102
Administration of Justice	53
Income Security	35
General government	18
TOTAL	$ 72,057

[33] Source: National Science Board, *Science and Engineering Indicators, 1991,* (Washington DC: U.S. Government Printing Office) 1991. (NSB 91-1). Note that these are functional budget categories, independent of the agency receiving the appropriations. Of course most of the defense function is in Defense, health research in the National Institutes of Health, etc.

4. Government Support for Commercial Technologies

a. Critical Technologies

Targeted investments by governments in specific technologies that might have been described politically as "critical" to some dimension of the national interest have a long, if sometimes checkered, history. In modern times three categories of technology have received the greatest attention:

* those deemed critical to national security,

* those inherent in nationalized or national-champion industries, and

* others not necessarily called "critical" but receiving high political priority as public goods (for example: air traffic control) or underpinning national projects such as manned exploration of space.)

Beyond these categories of specific technologies for national missions and public goods, most governments have indulged in a broad variety of subsidies for technologies of general economic interest. In some cases no specific technology, or even industry, is designated, as in R&D tax credits. In others an industry (computers, aviation, or health industry, for example) is selected for promotion on economic grounds, with the identification of specific technologies left to a process defined by policy and administrative procedures.

In the National Defense Authorization Act for FY 1989[34] the Congress mandated the Defense Department to provide Congress annually with a Critical Technologies Plan focusing on the 20 most critical technologies. The first such report (listing 22 technologies) was sent to Congress on 15 March 1989.[35] The statute defines critical technologies:

> "the technologies most essential to develop in order to ensure the long-term qualitative superiority of United States weapon systems."

The criteria given in the report for selecting technologies for the list are:[36]

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[34] Public Law 100-456, section 823.

[35] *The Department of Defense Critical Technologies Plan*, (Washington DC: The Department of Defense) 15 March 1989.

[36] *ibid*. page 5.

* Technologies that enhance performance of conventional weapons and provide new military capabilities;

* Technologies that improve availability, dependability and affordability of weapons systems.

The 1990 defense Critical Technologies List contained two additional criteria:

* Pervasiveness in major weapons systems, and

* Strengthening the industrial base to "reflect explicitly the growing concern for spin-off to the industrial base."[37]

As will be seen in the next section, these criteria could apply to the full range of defense R&D investments, and fail to provide much constraint on candidate technologies.

The selection of lists of "critical technologies" as preliminary to formulation of industrial policy first came into vogue in the late 1980s in the U.S.. Of course most nations have indulged in industrial policy, and insofar as they supported commercial technologies on the basis of a set of priorities, those selected might be considered more "critical" to national well-being than others. The Japanese have for some years engaged in net assessments of industrial technologies, a step that surely should be preliminary to the making of critical technology lists, and in collaboration with industry leaders have selected technologies for targeting. The choice of computer technology for the European Community's first "Framework" program: ESPRIT can be said to reflect the feeling that an indigenous computer industry is essential to European economies.

In the U.S.A. the origin of the critical technologies concept has its roots in defense technology policy. This is, perhaps, not surprising in view of the evolution of U.S. technology policy from defense-dominated to commercially-oriented. This origin in export control terminology will be significant when we discuss the meaning of the word "critical," which carries an implication that both security and economic interests are involved. This linking of military concerns with the desire to support industrial competitiveness suggests the danger that protectionist policies might become attached to those technologies deemed "critical" and receiving government subsidy.

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[37] Mary Ellen Mogee, *Technology Policy and Critical Technologies: A Summary of Recent Reports*, Discussion Paper No. 3, The Manufacturing Forum, (Washington DC: The National Academy Press) Dec. 1991.

i. Critical technologies as a concept for export control.

On Feb. 27, 1976, the Defense Science Board published a task force report, commonly referred to as the "Bucy Report" after the chairman, Fred Bucy of Texas Instruments Co., which recommended a radical reform of export control strategy.[38] It proposed that controls should be focused on retarding transfers of technology which could significantly enhance the military capability of potential adversaries. This strategy was seen as particularly useful when applied to turn-key facilities with which both weapons and civilian products could be produced. Thus the new policy would address a troublesome area not adequately dealt with in the Commerce Department's Controlled Commodities List: dual use technology.[39] Indeed, one benefit to industry was expected to be reduced reliance on the Controlled Commodities List. Three years would pass before these recommendations were embodied in export control law.

The Export Administration Act of 1979,[40] as amended in 1985, emphasized the control of critical technologies and assigned this responsibility to the Department of Defense. A key step was the creation by the Secretary of Defense of a "list of militarily critical technologies," which was published in both classified and unclassified form in October 1986.[41] This Militarily Critical Technologies List (MCTL) is not intended to serve as a "control list."

> "Rather it provides a detailed and structured technical statement of development, production, and utilization technologies which the Department of Defense assesses as being crucial to given military capabilities and of significant value to potential adversaries."[42]

It covers private as well as government-owned technologies. The statute says that primary emphasis shall be given, *inter alia*, to arrays of design and manufacturing know-how, keystone manufacturing, inspection, and test equipment, and goods accompanied by know-how or which might give insight

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[38] Defense Science Board, *Report of the Defense Science Board Task Force on Export of U.S. Technology*, (Washington DC: Office of the Secretary of Defense) Feb. 27, 1976.

[39] Dual use technologies are those applicable to both military and commercial uses. Post-cold-war U.S. military strategy is giving increased emphasis to command, control, communications, intelligence and logistics -- all areas in which commercial technologies are strong and defense technology investments are dual use.

[40] Export Administration Act P.L. 96-72.

[41] The classified MCTL was first published in 1980 and was revised five times by 1986. The first unclassified version was published in 1984. See, for example, the second unclassified version: Office of the Undersecretary of Defense Acquisition, *The Militarily Critical Technologies List*, (Washington DC: Department of Defense) October 1986.

[42] *ibid. p. ii.*

into design and manufacture of a U.S. military system. Thus the MCTL is not a list of critical military material and weapons systems. It is instead a list of technological capabilities, which in the hands of the industry in a potentially hostile state would give that state the capability to erode an advantage the first state perceives to be essential.

If the industrial capability in question has "dual uses," a factory possessing that capability can, in principle at least, produce civilian goods and/or weapons systems. The Controlled Commodities List did not have this property, for it refers to specific single products. A "militarily critical technology" is likely to include a family of tools and know-how which only in combination create the production capability in question. Increasingly, technologies of military importance are driven by huge commercial markets. In the last decade of the Cold War both nuclear weapons and their delivery systems were approaching both saturation and equality on both sides. Determinants of strategic advantage began to shift to command, control, communications, and intelligence. These functions all derive their primary technologies from the electronics, communications, and computer industries, where commercial technology leads the military by substantial margins. Thus these areas of strategic (and tactical) importance increasingly depend on dual use technologies.

Two consequences flow from this observation:

> a) The criteria for identifying a "critical" for export control purposes begin to resemble those one might apply in a policy designed to enhance commercial competitiveness.
>
> b) For this reason, and even as they cooperated in the COCOM export control regime, some trading partners of the U.S. became concerned that the MCTL might become an instrument of trade protection under the guise of a tool for protection collective security.

ii. Critical Technologies Reports

In the U.S. there have been two major studies leading to lists of "critical technologies" by private industry groups, two from government agencies (defense and commerce) and one mandated by Congress to be prepared by the Executive Office of the President.

In 1987, a private trade group, the **Aerospace Industries Association,** published a study made by many panels of experts from industry, universities, and government laboratories, identifying a number of technologies the industry considered "key" to its success.[43] The Association, headed by Donald Fuqua, retired chairman of the House Science, Space and Technology Committee, wanted to induce

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[43] Aerospace Industries Assoc., *Key Technologies for the 1990's: An Overview,* (Washington DC: The Aerospace Industries Association) 1987.

the government to recognize that the industry it represents has both commercial and military value, and that in promoting economic performance the government should support technology development as well as basic research. Although the technologies it analyzed were called "key" rather than "critical," the study was a prototype for those the Congress would soon ask for.

The Computer industry was not to be left behind. The **Computer Systems Policy Project (CSPP)** is comprised of the CEO and the CTO from each of 11 U.S. computer firms. Its 1990 report *Perspectives: Success Factors in Critical Technologies* identified 16 critical technologies for the future, and discussed the success factors that might guide public technology policy.[44]

Department of Defense Critical Technologies Plan: During the first Reagan Administration, the Department of Defense began to express its concern about the state of the civil economy and its future impact on defense should the decline continue. The Defense Science Board, in the study of dependency on foreign sources of supply for semiconductors, which later led to government support for the SEMATECH consortium, worried about the impact of lagging U.S. competitiveness on defense interests.[45] The Undersecretary for Acquisition and Logistics, Robert B. Costello, proposed that the Defense Department invest in the civil industrial technology base because defense production technology was dependent on it. These concerns energized Senator (D-NM) Jeff Bingaman, a member of the Senate Armed Services Committee and the Joint Economic Committee. He and his staff have authored a series of bills that led not only to the requirement for annual reports on defense critical technologies, but the creation of the Critical Technologies Institute to support officials in the Executive Office of the President and leading technology agencies with analysis to support policy making.

The Technology Administration of the Department of Commerce put out their own analysis in 1990, preferring to call its list the **"Emerging" Technologies Report.** Their criterion was the potential of the technology to contribute substantially to the economy over a ten year period. The criteria included:

* Potential market size;

* Contributions to productivity or quality improvement;

* Driving next generation R&D and spin-off applications.

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[44] Computer Systems Policy Project, *Perspectives: Success Factors in Critical Technologies*, (Washington DC: Computer Systems Policy Project) 1990.

[45] *Defense Science Board Task Force on Defense Semiconductor Dependency*, (Washington DC: Department of Defense, Defense Science Board), Feb. 1987.

The FY 1990 Defense Authorization Act contained an allocation from the Defense budget to finance a **Critical Technologies Panel** to be established by the **Office of Science and Technology** that would report biennially to the Congress on technologies critical to meeting national needs (competitiveness, defense, energy security, quality of life). Because any study made by OSTP of critical technologies might heighten pressure on the Administration to move toward what it felt was an unacceptable form of "industrial policy," the White House was quite nervous about the Panel's work. When the draft report appeared in the spring of 1991, an article appeared in the Wall Street Journal entitled "White House Tries to Distance Itself from Panel Report" and implying that the report was indeed a step down the slippery slope of industrial policy.[46] The pressure became quite intense; OSTP put out a press release disavowing any such intent, and all identification of OSTP or the Executive Office of the President with the report was deleted. The President's Council on Competitiveness, chaired by Vice President Dan Quayle, put out a Fact Sheet on April 25, 1991 that acknowledged the Panel Report and noted that technology creation was important but stated that, with certain exceptions, Administration policy was to leave this task to the private sector.

The second report in this series, prepared by a new panel under the guidance of OSTP, with the help of the new Critical Technologies Institute, was completed in December, 1992, and is expected to be published before the end of the Bush Administration on Jan. 21, 1993.

The private sector **Council on Competitiveness**[47] in March 1991, published a report entitled *Gaining New Ground*[48] which assesses the technologies in nine industrial sectors which, together, represent over $ 1 trillion in sales. "The sole criterion for choosing the following technologies is their importance for the competitiveness of the industrial sectors studied."[49] They identified the strengths and weaknesses of U.S. firms in the technologies identified, and made comparisons with the capabilities of firms in other nations. Finally the report recommends government actions in light of its findings. This listing of critical technologies has the virtue of less arbitrariness than many of the others. It begins with panels of experts examining each of the nine sectors without prior assumptions

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[46] Bob Davis, "White House Tries to Distance Itself from Panel Report," *Wall Street Journal*, April 26, 1991.

[47] Even Americans are confused by the three bodies with "competitiveness" and "council" in their names. The *Council on Competitiveness* is a non-governmental, not-for-profit group created by John Young, Chairman of Hewlett Packard Corp. The *President's Competitiveness Council* was chaired by Vice President Quayle and may not survive the transition from Bush to Clinton. The *Competitiveness Policy Council*, chaired economist C. Fred Bergsten, is comprised of both government officials and industrial and academic experts, and was created by the Congress in the Omnibus Trade and Competitiveness Act of 1988.

[48] *Loc. cit.*

[49] *ibid.* page 23.

about the value of the sector to government or national interest, other than the potential to create wealth and/or employment. Their recommendation is a five year implementation of a national program of investment in "critical generic" technologies. Its other recommendations deal with both diffusion strategy and R&D unlinked to the concept of critical technologies. Thus this report does specify what is to be done with the analysis, rather than leave the issue open.

iii. Creation of the Critical Technologies Institute

As the result of initiatives taken by Senator Bingaman, the Defense Department budget for FY 1991 contained authorization for a Critical Technologies Institute (CTI).[50] The CTI was to take responsibility for the biennial critical technologies panels established by OSTP, and the funding provided in the first year for the CTI was used to this end. However, the Institute was not established until October of 1992 because of reluctance of the Administration to see it created and of the Defense Department to see its funds used for this purpose. A lengthy negotiation between the Congress and Richard Darman, Director of the Office of Management and Budget, resolved the impasse in the following way: The CTI would be a Federally Funded Research and Development Center (FFRDC) administratively established and serviced by the National Science Foundation, but managed by a council chaired by the Director of OSTP, with membership from three other White House senior staff, together with senior officials from S&T agencies listed in the statute, provide policy direction for the Institute. Funds are transferred from Defense to NSF for the purpose. A competition for the contract attracted many applicants. The award was made to the RAND Corporation of Santa Monica, CA, which operates a substantial office in Washington DC. Dr. Stephen Drezner, VP for Research of RAND, serves as Director of CTI.

[50] National Defense Authorization Act for Fiscal Year 1991 (42 U.S.C. 6686).

iv. Technologies Appearing in the Lists

Mary Ellen Mogee has arrayed a table showing each of the above reports and the technologies they included in each of their analyses.[51] The matrix thus formed is remarkably dense; all the reports tend to pick the same technologies. Most frequently listed are:

* Materials: materials processing, composites, optoelectronics, microelectronics.

[51] M.E. Mogee, *loc. cit.* pages 16 and 17.

* Manufacturing: CIM, robotics, artificial intelligence.

* Information Technologies: High performance computing, displays, signal processing; human factors, networking.

* Biotechnology: medical applications.

* Aerospace: propulsion, surface transportation systems.

The main differences between the different approaches are: The private sector reports restricted themselves to their own industries. The defense list contains a number of specialized (and surprising to many) weapons systems, such as hyper-velocity projectiles and rail guns. The National C.T. Panel list is broadest, including energy and environmental technologies. All these reports focus on the very areas that have attracted the most commercial and government attention already. This tendency may reflect the desire of industry to see government contribute to their core technologies and of government agencies to protect their existing programs and budgets. But it did lead this observer to suggest a contrariant strategy:

> I have a problem ... with the temptation to restrict activities to the list of critical technologies officially promulgated by OSTP. I do appreciate the need to provide priorities for investment, but I strongly prefer a process for priority making that is flexible enough to identify new and exciting opportunities that might not be on someone's list.[52]

Authors at the RAND Corporation are preparing a study[53] for the OSTP Critical Technologies Panel on foreign targeting of technologies. They also observe that countries targeting technologies select essentially the same list that appears in the U.S. critical technology studies.

v. Criteria for "Critical Technologies Lists"

The world "critical" carries little meaning to support policy; it clearly implies high value, and implies that important strategic objectives may be unobtainable in its absence. Thus the loss of advantage in a "critical technology" might be thought a serious blow to the plans of its possessor. But criticality is clearly context specific. Insulin is critical to a diabetic, but to no one else. The patent on the use

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[52] L.M. Branscomb, Testimony at hearing on H.R. 5231: the National Competitiveness Act of 1992, before the Subcommittee on Technology and Competitiveness, Committee on Science, Space, and Technology, U.S. House of Representatives, June 3, 1992.

[53] unpublished at this writing.

of Selenium as a photoconductor was critical to Xerox, until the day the 17 year patent ran out, but Selenium would not be a critical material in the Defense Department's inventory of critical materials. A lithography system capable of patterning 0.35 micron circuit elements on a Silicon wafer will be a critical technology to a microchip manufacturer, and probably to the nation whose industry enjoys strength as a microelectronics producer, but not to equally strong economies that are content to buy their chips from others.

Thus an economist might try to calculate the economic return from a technology, and identify as critical the civilian technologies of greatest economic importance. A scientist will consider critical those tools without which his science cannot be explored. An historian might consider critical a technology whose introduction had the most profound effect in shaping the mores and institutions of society.

Corporations have diverse approaches to attaching strategic priorities to technologies. We can divide industries into two groups: those most sensitive to monopolies based on legally protected intellectual property, such as pharmaceuticals and software, and those with broad ranges of technical choice. The former group will, quite obviously, consider as "critical" those patents or copyrights that preserve the opportunity to set prices on product value rather than on cost. The latter group of companies will view "criticality" in terms of its business strategy. If the firm characterizes its business as defined by its core technologies, the method of selection of those technologies will define "criticality." The NEC corporation, for example, has a planning methodology which selects from among its available technology futures the smallest number that support access to the broadest range of possible markets. A "market defined" firm in the same industry, however, will select as critical to its future those technologies that, through diversification, best protect its markets from attack by firms from outside the industry.[54] The selection each makes may be quite different.

A military organization will consider critical those technologies not yet available to potential adversaries that provide the largest qualitative superiority to its forces, independent of cost. Because such advantages are transient, special importance will be attached to any critical set of tools, materials, or process equipment without which a weapons system providing qualitative advantage cannot be produced. Thus, economic return may be of minor interest. An example would be the U.S. claim that the sale of highly specialized Toshiba machine tools through a Norwegian intermediary to the Soviet Union enabled the USSR to substantially erode a qualitative advantage in quietness of the U. S. submarine fleet.

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[54] L. Branscomb and F. Kodama, *Managing Innovation and Setting Technology Strategy in the Japanese Electronics and Energy Industry: Some Insights for Further Exploration*, to be published 1993.

A government, concerned primarily about sustaining the competitiveness of its commercial industry and contemplating initiatives in technology policy, will have yet another set of criteria for defining a "critical technology." These criteria might be based on four sets of criteria: value, opportunities for advantage, opportunities for government influence, and appropriateness for government promotion.

> **Value of a technology:** What opportunities for job and wealth creation in domestically located industry are inherent in the technology? What is the breadth of leverage of a technology?
>
> **The opportunities for differential advantage:** Is there enough technical challenge in the technology, or enough opportunity for intellectual property protection, to provide first mover advantage to the successful innovator?
>
> **The opportunity for a government to influence progress:** Would actions by government, such as investing in R&D, targeting procurement, setting standards or providing financial incentives, have the power to influence the rate of commercial progress?
>
> **The appropriateness of federal action**: If the answers to questions 1, 2, and 3 are affirmative, there remains the question whether such government action is appropriate, under economic theory for a competitive market economy and under fairness principles in a democracy. The key issues are likely to be:
>
>> Does the technology, at its current stage of development, exhibit sufficiently low appropriability that private investment will be insufficient to advance it at a satisfactory rate?
>>
>> Does the technology have a high enough rate of social return to justify the public investment, either through economic return to the economy or through provision of public goods?

In none of the eight U.S. studies that have led to lists of critical technologies have such a set of criteria been used in any formal sense. Thus one cannot draw the conclusion that having drawn such a list, it follows that government should invest in the technologies on the list. Nor does existence of such a list suggest what actions government would be justified in taking.

In one sense the adjective "critical" is a qualifier on the government role in direct support of the civil technology base, admittedly an imprecise and ambiguous qualifier. Whatever attributes are associated with the term, they tend to convey a sense of *priority*. A list of critical technologies fails to convey any distinction, however, between the role of government and that of the commercial or education sectors, or the states.

"Critical" does not define *appropriateness* of a government investment in private sector R&D. Appropriateness has two attributes: (a) the fairness of the process of selecting private organization to benefit from public funds, and (b) the avoidance of substituting public for private funds, ie. investing in public goods. Fairness is a matter of process; restricting government support to public goods rests on economic criteria. These criteria stress low appropriability to the firm in the presence of high social return.

b. Criteria for Government Support

i. "Precompetitive," "Generic," "Strategic," "Enabling," "Pathbreaking," and "Infrastructural" technologies

In the search for simple concepts that capture appropriateness and fairness, the Congress and the Administration have used terms such as "pre-competitive" (to suggest non-distortion of the market), "generic" (to suggest ubiquitous utility), "enabling" and "infrastructural" (to imply indirect contributions to productivity and to the innovation process.

> **Generic technology** is defined by the Department of Commerce as:
>
> "...a concept, component, or process, or the further investigation of scientific phenomena, that has the potential to be applied to a broad range of products or processes."[55] (Thus generic technology is at the applied end of a spectrum of useful, but generally non-proprietary knowledge that begins with basic research but extends to tools, methods, materials, and basic processes.)
>
> **Precompetitive technology** is defined the Department of Commerce as:
>
> "...research and development activities up to the stage where technical uncertainties are sufficiently reduced to permit preliminary assessment of commercial potential and prior to development of application-specific commercial prototypes."[56] (There is an implicit assumption that when consortia of competing firms are eager to collaborate in a government project, while fully aware of anti-trust limitations, the project is pre-competitive.)

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[55] Title 15 of the Code of Federal Regulations, section 295.2 (b), under 15 U.S.C. 271 et seq. and section 5131 of the Omnibus Trade and Competitiveness Act of 1988 (P.L. 100-418).

[56] *ibid.* section 295.2 (g).

Thus, as noted above, the Advanced Technology Program is restricted to "pre-competitive generic" technology. Two other categories of public good technology are recognized.

> **Pathbreaking technology** is defined by the authors of *Beyond Spinoff* as:
> High-risk technologies with long delayed (if ever) payoff, but the potential to create new markets and even new industries.[57] Because such projects are close to the frontiers of basic science and are often glamorous, they are popular with government agencies. They are also close in spirit to cold war technology policy traditions, and exploit the linear, or pipe-line model of innovation. The best current example of government support for a pathbreaking technology is bio-technology, with much of the stimulation for the new industry coming from biomedical research at the National Institutes of Health. A second example, much less likely to be equally successful, is high temperature superconductivity.
>
> **Infrastructural technology** is similar in concept to generic technology in its focus on tools and techniques, but also includes technology to support services that comprise the information infrastructure.[58] As noted in the next section, one of the limitations of the focus on critical technologies is its failure to suggest the importance of technology diffusion. Infrastructural technology is best characterized by the work the NIST (formerly National Bureau of Standards) and the National Advisory Committee for Aeronautics (now part of NASA) have done for industry over many decades: developing tools, instruments, and test methods, characterizing materials and processes, and evaluating and disseminating technical information.

Third, there is:

> **Strategic technology**. This label is context dependent. Firms use "strategic technology" to refer to the core competence of the firm. In that sense the notion of criticality comes into play. The National Science Foundation considered altering its taxonomy for R&D by introducing the idea of "strategic research" to cover much of what is more often called "generic" or "infrastructural," leaving "applied research" to refer to problem solving research. The authors of *Beyond Spinoff* used "strategic technology" to imply a government industrial strategy. In

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[57] John Alic, Lewis M. Branscomb, Harvey Brooks, Ashton Carter, and Gerald Epstein) *Beyond Spinoff: Military and Commercial Technologies in a Changing World (*Boston: Harvard Business School Press), April 1992.

[58] L.M. Branscomb, "Information Infrastructure: A Public Policy Perspective," Brian Kahin, Ed., *Building Information Infrastructure: Issues in the Development of the National Research and Education Network*, New York: McGraw Hill, December, 1991.

unusual cases an industry under severe competitive pressure might be considered "critical" to the national security or welfare, justifying a government investment in industry-specific technology. The authors warn that this policy comes closest to displaying the attributes of industrial policy to which most Americans object. The way the Sematech investment was presented to government in the beginning had much of this flavor, for the justification for a government investment (by DARPA) of $ 100 million a year rested largely on a Defense Science Board study of the security threat from foreign dependency in the semiconductor field. (See section 4.c.ii) A current evaluation of what Sematech is doing might well characterize the investtment as "infrastructural," since it is aimed primarily at industry-wide technical standards for incorporating new production tooling into an advanced semiconductor manufacturing line.

ii. The Commerce Advanced Technology Program (ATP).

The Advanced Technology Program, managed by the National Institute for Standards and Technology (NIST) in the U.S. Department of Commerce, provides cost-shared funding to commercial firms, or consortia of firms, in support of commercially relevant technology. The budget request for this program in FY 1993 is $ 69 million. As currently administered the program does not give priority to any list of "critical technologies," even though NIST provided such a list two years ago. Instead the program is open to unsolicited proposals from firms for work in what the Commerce Department calls "high-risk, high-return research on pre-competitive, generic technologies."[59] In the following section the official definitions of these terms will be discussed. Note that the term "generic" seems to be in conflict with the words "high-risk, high-return."

Proposals found within the constraints of these definitions are subject to a review process that first scores the projects for technical excellence. Those found excellent are reviewed for their business promise and the capabilities and commitment of the proposing firm(s). Thus the selection process serves up projects that do not *a priori* follow any list of pre-determined critical technologies.

iii. The SBIR program.

In 1982 the Congress passed a statute at the urging of the small business lobby called the Small Business Innovative Research Grants Program.[60] The statute requires all federal agencies funding research on contracts or grants to invest no less than 1.25 percent of this activity in qualifying small businesses. A small business is defined as a firm with less than 500 employees, although most such

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[59] *Strategic View*, Technology Administration, U.S. Department of Commerce, Nov. 1991, page 25

[60] Small Business Innovation Development Act of 1982, Public Law 97-219.

firms have less than 25 employees. There are no criteria for the kind of work these firms are to be asked to do other than the agency's mission; the assumption is that small businesses can contribute effectively at least to the extent of 1.25 percent to whatever R&D the agency is conducting. In 1989, the last year for which data are available, some $ 432 million was spent in SBIR, for a cumulative total of $ 1.8 billion. Initially the SBIR program was strenuously resisted by the agencies, which saw it as yet another example of "pork barrel" legislation and a constraint on their autonomy. However, it has proved as politically attractive to the agencies as to the Congress, and objections have faded. The program is designed so that the initial contract or grant is quite small: about $ 50,000. But if the R&D project is successful, a second grant of five times as much can be made to facilitate commercialization of the new technology.

SBIR is one of the few programs in which federal funds are made available to private firms and may be used to support the development of a commercial product. The justification for this market intervention by government is based primarily on the assumption that the development in question was required to fulfill an agency mission. In the case of the Department of Defense, the product might be something the Department wishes to purchase for the military services. But this justification does not apply to the NSF; there the justification is simply political. The NIH is a special case however; its grants can contribute directly to the creation of new biotechnology ventures.
During the presidential campaign Governor Clinton stated his intention to double the size of the SBIR program, raising the minimum percentage to 2.5 percent. SBIR grants can also work synergistically with Cooperative Reserach And Development Agreements (CRADAs), as small firms receive support for research while collaborating with a national laboratory under a CRADA arrangement.

c. Institutional Choices

Once policy criteria for investments in civilian R&D are defined, the institutions to perform the R&D must be selected and the mechanisms for selected and funding them chosen. Two sets of institutional choices must be made:

> * What civilian agency -- new or existing -- will be given responsibility for managing the civilian industrial R&D programs?
>
> * What institutions will be relied on for the performance of the civilian R&D -- firms, or groups of firms; national laboratories; universities; or combinations of them?

First, let us consider the choice of federal agency.

i. A New Civilian Technology Agency?

On November 21, 1989, Senator John Glenn, Chairman of the Senate Governmental Affairs Committee, introduced the "Trade and Technology Promotion Act of 1989" (Senate 1978). The purpose of this bill was to create in the Department of Commerce an "Advanced Civilian Technology Agency," to support technologies for commercial industry by analogy to the Defense Department's Advanced Research Projects Agency (DARPA).[61] ACTA proposed to create a revolving fund to support cost-shared public-private partnerships. This proposal, which was not enacted, is one of many that seek to enlist DARPA in the government's competitiveness strategy or clone it in a civilian agency such as Commerce. A number of proposals have been made to create a "civilian DARPA" or "CARPA." Another proposal, from the Carnegie Commission on Science, Technology and Government, suggested that emphasis be given to the dual-use technology mission of DARPA, changing its name to "NARPA": the National Advanced Research Projects Agency[62] in recognition of its dual use activities and new authority to combine efforts with civilian agencies investing in the same technologies. In the FY 1993 defense appropriation, Senator Bingaman found a more acceptable name: reversion to the agency's original name ARPA. A strong case for chartering ARPA with an explicit dual-use technology development mission is made by Jeff Bingaman and Bobby R. Inman.[63]

This fascination with DARPA as a model for an agency to make investments in the civil industrial technology base has three roots.

* DARPA enjoys an R&D budget of about $ 1.5 billions, 30 times the size of Commerce's Advanced Technology Program.[64]

* DARPA has a small, technically expert staff, with a reputation for low overhead and quick decisions.[65] (Contracting is largely through acquisition offices in the military services.)

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[61] *Managing Critical Technologies: What Should the Federal Role Be?*" (Washington DC: The Conference Board) Research Report No. 943, Dec. 14, 1989, page 4.

[62] *Technology and Economic Performance* (New York: Carnegie Commission on Science and Technology) 1991.

[63] Jeff Bingaman and Bobby R. Inman, "Broadening Horizons for Defense R&D," *Issues in Science and Technology*, Vol. 9, No. 1, Fall 1992, page 80-85.

[64] In FY 92 DARPA's budget of $ 1,586.3 millions was comprised as follows: Research $ 115.8 m; exploratory development $ 744.4 m; advanced technology development $ 657.6 m; and management and support $ 68.5 millions.

[65] FY 92 personnel: 142 civilians, 25 military, 16 IPAs, total of 183. But 2/3 of DARPA's expenditures are contracted by service and other agencies for DARPA, which minimizes DARPA's

* DARPA's role is investment in technologies of military potential far in advance of established service requirements; it enjoys a high degree of latitude in deciding what these technologies will be.[66]

Of course, there is no reason to believe that calling a new civil agency ACTA or CARPA would earn it a $ 1.5 billion budget, or that managers of a civilian agency could ever enjoy the freedom of action of DARPA's managers, who are cloaked in the autonomy that national security uniquely imparts. Indeed, there are many skeptics about the appropriateness of the concept of a "civil DARPA." One view is to question whether a government agency can do a better job than a sector-specific venture capital or mutual firm at making technology investments in a commercial market.[67]

Another attempt to invent a civilian technology agency free from political interference has been proposed by a report of the National Research Council.[68] The Research Council's Panel on the Government Role in Civilian Technology recommends that a Civilian Technology Corporation (CTC) be chartered by the Congress and governed by a board appointed by the President and confirmed by the Senate. It would receive a one time appropriation of $ 5 billion in public funds, and would have the authority to make venture capital investments as well as R&D grants and contracts. This "arm's length" relationship to government would, advocates say, increase the likelihood that bold and non-political choices of technology investments would be made. Critics point to the suggestion that the board of directors of the CTC, not the President, would appoint the CEO. They recall the reason President Truman vetoed the original bill to create the NSF (then called National Research Foundation). President Truman insisted that if public funds were to be expended, the CEO must be accountable to him, just as the President was accountable to the Congress and the people for the use of their tax monies. He had his way in the present form of the National Science Foundation.

ii. Industrial Consortia: Anti-trust

Interest in encouragement of industrial alliances and consortia has grown rapidly since 1980 under the following influences:

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administrative burden.

[66] However, the strongest complaint about DARPA's effectiveness is its success at winning adoption of the technologies it promotes into the weapons systems of the three military services.

[67] George Donohue, Richard H. Buenneke,Jr., and Wayne G. Walker, "Why Not a Civil DARPA?" *Rand Issue Paper*, Vol. 1, No. 1, Nov. 1992. (Santa Monica, CA: RAND Corporation).

[68] Committee on Science Engineering and Public Policy, *The Government Role in Civilian Technology: Building a New Alliance*, (Washington DC: The National Academy Press) April 1992.

* If government gives R&D subsidies directly to industrial firms, there immediately arises an issue of "fairness." If the benefits flow to a consortium of firms that is open to all who qualify,[69] instead of to a single selected firm, the government is much less likely to be criticized for interfering unfairly in market competition.

* In the face of strong foreign competition, firms are increasingly looking to industry-wide (horizontal) consortia to sustain essential elements of the infrastructure and the sources of technical knowledge on which they depend.

* U.S. firms, observing the strength of the Japanese kieretsu, are increasingly aware of the power of strong vendor - manufacturer relationships, and are looking to vertical alliances in preference to being vertically integrated.

* Since the advent of the Reagan Administration in 1980, anti-trust enforcement has been moderated and the Justice Department is increasingly willing to evaluate industry concentration in the world market, rather than the domestic market only.

This trend began with the formation of the Microelectronics and Computer Technology Corporation (MCC), which was not initially seeking a federal subsidy but did lobby for passage of the Cooperative Research Act of 1984.[70] For qualifying R&D consortia registering with the Department of Justice, this statute eliminates the threat of treble damages in Federal anti-trust actions. Today, MCC is focusing much of its attention on enterprise integration through computer networks and other elements of infrastructure for the more than 80 participating firms.

In 1987 a group of 14 semiconductor manufacturers organized SEMATECH, the Semiconductor Manufacturing Technology Corporation, to improve semiconductor manufacturing. The primary concern of the consortium was the inability of the small and undercapitalized manufacturers of production tooling to keep up with the fast pace of miniaturization of microelectronic circuits, increases in wafer size, and escalating requirements for low defect rates. At the same time this consortium was being organized the Department of Defense, concerned about the rapid loss of market share to Japanese semiconductor producers, made a study of the consequences to the U.S.

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[69] A politically troublesome issue concerns the treatment of foreign-owned U.S. firms, and specifically the wholly-owned U.S. subsidiaries of foreign multinationals. They are sometimes excluded from government-assisted consortia, but pressures are increasing to base the criterion for participation not on ownership, but on constructive contributions to the U.S. economy (local content, hiring of U.S. nationals in management positions, etc.) See Robert Reich, "Who's Us," *Harvard Business Review*, Jan. 1990.

[70] Public Law 98-462, 15 U.S.C. 4301-4305.

military position if it became excessively dependent on foreign sources of supply for semiconductors.[71] Noting that semiconductors are a prime example of a dual use technology, the DSB report recommended DoD support of an effort to ensure the survival of a viable U.S. industry. In FY 1988 the Department of Defense, through the Defense Advanced Research Agency (DARPA) began matching the private industry investment in SEMATECH with annual support of $ 100 million. SEMATECH has enjoyed some success in its efforts; in late 1992 the U.S. share of the world merchant semiconductor output reversed its downward trend and rose to be marginally higher than the Japanese share. The government investment in SEMATECH is, perhaps, the closest example in U.S. experience to a "strategic technology" investment, as described in IV.B.1.

The Commerce Department's Advanced Technology Program, described in IV.B.2., is open to unsolicited proposals from single firms or groups of firms. All of the projects require at least equal cost sharing by the industry. As a practical matter all ATP contracts with single firms are with small to medium sized businesses, and the program clearly prefers multiple company participation especially when one or more large firms are involved.

There are now a growing number of examples of technology-specific projects in which a government agency collaborates with several industrial firms in a project of national interest. After the discovery of High Temperature Superconductivity, the Office of Science and Technology Policy encouraged several agencies to initiate consortia of firms, universities and national laboratories, with government funding supporting the university and national laboratory partners. The Department of Energy supports a technology effort in cooperation with the "big three" U.S. auto makers and an number of other firms to develop batteries for electric vehicles. A third example is the National Center for Manufacturing Sciences in Michigan, which with 130 members develops and deploys technologies for world-class manufacturing.

From a technology policy perspective, federal support for consortia are a way of encouraging technology diffusion concurrently with technology generation, and is thus a hybrid supply- and demand-side approach. However, each of the examples of government participation, ATP excepted, have been *ad hoc* initiatives, usually from the private sector. Each may be a legitimate experiment in technology policy, and more likely to be successful because of the industry commitments to success. But Guston's warning that the distinction between such projects and Congressional

[71] Department of Defense, *Defense Semiconductor Dependency: A Report of the Defense Science Board* (Washington DC: DoD, Office of the Under Secretary for Acquisition) February, 1987.

"earmarking" of funds for favorite constituents in home districts may become thinner should be heeded.[72]

iii. National Laboratories: future missions.

As the incoming administration addresses the way the government's R&D resources are allocated, it will have to review the complex of over 700 federally supported research and development laboratories.

Table 1

Federal Obligations for R&D by performer, FY 92 (est)[1]
$ millions

	Total	Intram	Indust.	Univ.	FFRDC	Other
Total: All Agencies	70,427	17,645	31,929	10,475	7,216	3,160

[1] From National Science Foundation, *Federal Funds for Research and Development: Fiscal Years 1990, 1991, and 1992.* Volume XL, NSF 92-322 (Washington DC: National Science Foundation) 1992, page 51.

Of last year's (FY 1992) expenditures of $70.4 billion spent on R&D, some $ 24.86 billions --a third of the total) are spent in laboratories funded in their entirety by federal agencies (i.e. the federal intramural laboratories and the captive contract labs, the FFRDCs).

Diversity is the hallmark of scientific or engineering laboratories. An attempt to classify both public and private laboratories by their environmental influences has been made in an extensive set of surveys of over 1,300 laboratories has been made in the National Comparative R&D Laboratory Project (NCRDP).[73]

The largest federally-financed research and development laboratories -- not associated with profit-seeking defense contractors -- with the most diversified technical capabilities are called "national

[72] "Earmarking" - a form of "pork barrel" politics committing federal funds for R&D or research facilities without the project submission to agency processes - was discussed in section 2.c.

[73] Michael Crow and Barry Bozeman have carried out the NCRDP program since 1984. The taxonomy presented here is from Crow and Bozeman, "R&D laboratories in the U.S.A.: structure capacity and context" *Science and Public Policy*, vol. 18, no. 3, June 1991, pp 165-179.

laboratories."[74] While the definition is rather imprecise, the "national laboratories" label brings most often to mind laboratories associated with DoE, NASA, NIH, and NIST and NRL. In this list there are two different forms of institutions:

* contractor-operated laboratories like those of the DoE, most of which are government owned (GOCO), and other laboratories owned by not-for-profit companies (such as MITRE and Aerospace Corp.).[75] Among the contractors are industrial firms, universities, and consortia of universities;

* government-owned, government operated (GOGO) laboratories like NIST, NRL, NASA, and NIH, in which the staffs are predominantly or at least substantially comprised of government employees.

This second group exhibits many variations. The NASA enabling statutes provide some special flexibilities in their personnel policies, relative to the majority of government civil service positions. This is true to a lesser degree at NIST as well. Furthermore most NASA centers have a core staff of government employees, whose number has been shrinking, surrounded by a large and growing staff of contractor support people. NIH also enjoys special legislation for their scientific staffs, over and above the unique nature of the Public Health Service on which NIH is based. The NASA laboratories are also of two types: the space mission laboratories: Goddard, Huntsville, Marshall, and Cape Canaveral; and the aeronautical laboratories: Langley, Ames and Lewis.

A special kind of federally supported research laboratory is the Federally Funded Research and Development Center (FFRDC). These are not-for-profit contractor-operated research groups serving a single agency's mission in support of that agency's decision making. Some FFRDCs are embedded inside other institutions. There are 3 serving different clients inside MITRE (FAA, Army, and

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[74] It is, perhaps, surprising how difficult it is to create an unambiguous definition that isolates "national laboratories" from other federally funded technological institutions, even though most people will give the same list when asked to name them. For example, many are included in the list of FFRDCs (Federally Funded Research and Development Centers), but many FFRDCs are embedded in other not-for-profit technically staffed institutions, which are not themselves FFRDCs. Furthermore, some national laboratories, such as NIST and NIH, are directly operated by federal agencies and staffed with civil servants; others are contract operations managed by universities or by profit seeking defense contractors.

[75] The DoE laboratories are of two types: the weapons labs: Livermore, Los Alamos, Sandia, and the multifunctional research laboratories: Fermilab, SLAC, the Berkeley Radiation Lab, Argonne, Brookhaven, and Oak Ridge.

Airforce),[76] several inside the RAND corporation. The FFRDCs come closest to carrying out functions akin to that conducted by government officials: aimed at decision support than the creation of technologies and artifacts.

Another kind of national laboratory is the scientific facility, where the cost of a leading edge facility is such that sharing among all researchers is necessary. These include optical and radio astronomy observatories, particle accelerators for high energy physics, fusion energy research facilities, oceanographic ships and their support facilities, climate and weather research facilities, etc. These kinds of facilities must be continued and kept up to date, and from time to time new ones established, if the U.S. is to maintain a leadership position in the observational and many of the engineering sciences. While their capital costs are sometimes very large (SSC is an extreme case) their operating costs are usually modest in comparison. In the discussion that follows I will focus attention on the DoE nuclear weapons laboratories. It is the combination of their huge costs and a mission of diminishing scale that creates a policy problem.

Concerns about the federally funded R&D laboratories have a long history, quite a apart from the current sea-change in federal technology policy. The most recent study at the level of the Executive Office of the President was carried out in 1983 by the Federal Review Panel, chaired by David Packard, for the White House Science Council.[77] Appendix C of their study lists a selection 39 prior studies. Virtually every review of the federal and national laboratory system concluded that most of the laboratories are substantially (and in some cases purposefully) isolated from commercial industry. Second, industry experts testify to the great difficulty and risk of commercializing new scientific ideas. Even within a single company, such as IBM or GE, moving new technology from Corporate Research to any of the firm's product development and production divisions requires the full time attention of very experienced managers. Even then success is very chancy.

(1) Suitability of National Laboratories for Economic Mission

To what extent are the financial and human resources devoted to these laboratories appropriate for the new situation? Are their missions, their organizational forms and locations, and their relationship to other technical institutions both public and private appropriate? The incoming administration will

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[76] At an earlier time all of MITRE would have been considered an Airforce FFRDC. It grew by adding contract work for other military and civil agencies, and some of that work became converted into the FFRDC form.

[77] David Packard, panel chair, *Report of the White House Science Council: Federal Laboratory Review Panel*, (Washington DC: Office of Science and Technology Policy, Executive Office of the President) May 1983.

address its choices in technology policy with several constraints posed by this spectrum of laboratories, some imposed by circumstances, others by policy choice:

> A) Because of the deficit new and additional R&D resources will be scarce; resource allocation strategies will involve reprogramming and seeking greater leverage from current funding. Federal directly operated and "national" laboratories receive, in the aggregate, about 28 percent of the federal R&D budget.[78]

> B) Federal policy for enhancing economic performance through R&D investment focuses on private industry as the primary source of innovations and the beneficiary of federal civilian technology programs. Technology policy will be an enabling policy, emphasizing public investments to enhance economic performance through knowledge creation, education and training, and technology diffusion to and within the private sector.

> C) Given the pressure on defense resources, the strategy will have as a long term goal building a common industrial technology base for both commercial markets and governmental (military and other) missions. The focus for this objective will be dual use technology. National laboratories develop technology applicable in both civil and defense sectors, although the largest laboratories (the DoE weapons labs) serve defense-related missions.

Because of (A) it is important to address the current allocation of federal R&D resources. Of the current annual expenditures of $75 billion [get 1992 no's] some $ 20.8 billions --almost 30% of the total) are spent in laboratories funded in their entirety by federal agencies.

There are strong political pressures to retain the rates of expenditures in the national laboratories, despite their fading missions, by authorizing the laboratories to invest in civilian technologies in collaboration with private firms. The Senate passed a bill in the summer of 1992, "The Department of Energy Laboratory Partnership Act of 1992" (S-2566), which would authorize just that. The Bush administration has strongly encouraged the formation of "CRADAs" (Cooperative Research and Development Agreements, authorized in the 1986 Stevenson-Wydler amendments). The Clinton-Gore Technology Policy statement proposes that 10 to 20 percent of DoE laboratory budgets should be devoted to cooperative R&D with commercial firms. Thus, despite the laboratories' relative isolation from commercial innovation, those interested in preserving laboratory budgets and those eager to demonstrate quickly a means for linking federal R&D to commercial firms share a common interest in this policy direction. Opposed to them are those who see the $20.8 billions spent in

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[78] About $ 20.8 billion of the total federal R&D expenditure in 1992 of $ 75 billion is devoted to federally funded laboratories.

government laboratories as exacting a major opportunity cost inhibiting new initiatives targeted at the civilian industrial technology base.

(2) Alternative policy solutions.

Given the size of the labs and the scale of their resources, it is very unlikely that any one policy solution to either re-missioning or down-sizing will prove adequate or appropriate. Thus the following alternatives are likely to be used in combination:

> **Muddle along**: Make the Stevenson-Wydler Act approach work in context of the labs as they are. While politically the easiest alternative, this approach is not regarded as likely to be sufficiently productive to justify the continued cost of the laboratories.
>
> **Triage:** Shrink the labs dramatically, using a political mechanism akin to the Military Base Closing Commission, and release the excess resources of money and people to the market. While politically unrealistic, this is the course economists would advocate.
>
> **Expand work scope:** Find new federal missions for the labs within the agency legislative mandate. (Energy; automotive; environmental). Dedicating the laboratories to such expanded efforts leaves unsolved the partnership with industry required to ensure they meet economic and market realities.
>
> **Privatize:** Change the enabling statutes to authorize the labs to perform "R&D for hire" and reduce their federal support as industry funding rises; alternatively try to sell portions of the labs, with their people and facilities, to industry consortia. Britain tried this after the Rothschild White Paper, and many other countries with large laboratories (such as Australia) have tried too. The transaction costs to the firms are simply too high to use such labs profitably.
>
> **Legislate a New Mission in Civilian Technology:** Charter the labs to respond to industry initiatives and to pursue development of industrially relevant technology. If the Congress authorizes the labs to spend public funds on commercial activities, there must be some policy constraints to limit the inevitable perception that public funds are simply being diverted for private gain. Even if this does not create complaints of unfair, government-sponsored competition, it may invite a level of "earmarking" not yet experienced.
>
> **Reassign Labs to New Agency or to Commerce:** Change the enabling statutes to shift one, or a few labs, with their budgets in tact, to another institutional setting where conditions for effectiveness are better: the obvious candidate is NIST. This idea requires a degree of

willingness of Congressional committees to transfer both money and "turf" to one another that is not regarded as likely.

iv. Universities: University-Industry Research Centers

The third institution that can serve to collaborate with federal civil agencies in the creation of technology of economic value is the university, or at least parts of the university (engineering, business, and some natural and social sciences in particular). The universities, beholden to both federal and state governments for financial support, have tended to exaggerate the extent to which they offer the solution to the nation's competitiveness problems.[79] There are rather severe limits to the extent universities can engage in commercially related activities, and many are testing those limits today.

A study for the Ford Foundation under the direction of Prof. Richard Florida, *et al.* at Carnegie Mellon University has searched out all the University-Industry Research Centers, and found 1,050 of them, spending $ 4.5 billions annually.[80] This funding comes from federal agencies (34.1 %); industry (30.7 %); the universities themselves (17.7%); and from state governments and other sources (17.5 %). The distribution of support across federal agencies is surprisingly uniform and reflects widespread multiple support. the following percentage of centers receive support from the respective agencies. NSF (54.9 %), Defense (45.1 %), Energy (33.9%), NASA (27.3 %), and NIH (26.7 %).[81] The industry coverage is quite broad too, spanning chemicals, pharmaceuticals, computers, software, electronics, petroleum and coal. Even more impressive is the finding that 57.9 % of the centers were founded between 1980 and 1989; the phenomenon seems to be growing quite rapidly. This study strongly suggests that the universities are more deeply engaged in relationships with industry than most people thought. One implication the study is that some 13.3 percent of science and engineering doctorates in U.S. universities may have exposure to industrial culture through participation in one of these University-Industry centers.

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[79] Brooks, Harvey, "University-Industry Cooperation as Industrial Strategy," chapter 4 in S. B. Lundstedt and T.H. Moss, eds., *Managing Innovation and Change*, Dordrecht, Netherlands: Klewer Academic Publishers, 1989, pp. 35-46.

[80] Wesley Cohen, Richard Florida and W. Richard Goe, *University-Industry Research Centers in the United States*, Center for Economic Development, Carnegie Mellon University, A Report to the Ford Foundation, June 1992.

[81] These percentages add to 187.9 %. The centers were asked from what agencies they receive support. The data show that on average each center is supported by at least two agencies. The figures do not suggest that the agencies are all investing in centers at comparable levels. An agency like NSF may support more than half of the centers, but it may do so with very modest grants.

The greatest value of this level of university involvement with industry is access by the university's science, engineering and management students to industrial culture and problems and the access the participating firms have to students whom they can recruit into their employ. Through the students, universities represent a uniquely effective mechanism for technology diffusion.

How the universities and government will work out their new relationship, with industry as a participating third party is the subject of section 6.

5. Government Promotion of Technology Diffusion

The search for a political and economic middle ground between a laissez-faire economic policy and a full-blown industrial policy made little progress until quite recently. A new approach, which appears to have the makings of a consensus, urges the development of a U.S. "technology policy," in which the federal government helps develop and provide access to the technical knowledge on which the competitiveness of commercial enterprises and the productivity of all U.S. institutions depend. Among the advocates of an explicit technology policy are science and technology policy scholars, civilian high-tech industry executives (including members of the private Council on Competitiveness), some micro-economists, and influential technology advocates within the Bush administration, including the Assistant to the President for Science and Technology, D. Allan Bromley, and leaders in many technology-intensive agencies and departments.

Allan Bromley, speaking for the administration, made himself the leader of this middle-ground approach by sending to the Congress in September, 1991, a formal document entitled "The U.S. Technology Policy.[82]" Washington wags said that the most important thing about this little-publicized report was its title page.[83] But a team headed by James Ling staffed from Bromley's Office of Science and Technology Policy (OSTP) and Richard Darman's Office of Management and Budget (OMB) spent 14 months crafting the policy and gaining its acceptance. Building a consensus in the White House for any document with the words "technology policy" in the title was no small achievement.

Beyond establishing the political legitimacy of technology policy, this document advances a technology policy that, at least in its principles, represents an important departure from the 40 years since World War II. This policy has the hallmarks of a "diffusion-oriented" policy.

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[82] *The U.S. Technology Policy,* (Washington, DC: The White House, September 26, 1991).

[83] The administration has been very reluctant to embrace the idea of "technology policy" for fear that it would encourage Congressional pressure for federal research and development activities that might distort the market, interfere with private business decisions, and prove wasteful of federal resources -- in short activities that border on "industrial policy."

The five primary goals of U.S. technology policy, as formulated in this document are:

* A quality work force that is educated, trained, and flexible in adapting to technological and competitive change;

* A financial environment that is conducive to longer-term investment in technology;

* The translation of technology into timely, cost-competitive, high-quality manufactured products;

* An efficient technological infrastructure, especially in the transfer of information; and

* A legal and regulatory environment that provides stability for innovation and does not contain unnecessary barriers to private investments in R&D and domestic production.

The first, third and fourth of these goals focus on increasing productivity through enhanced diffusion, with the latter specifically relating to NREN computer network. The policy statement also calls for collaboration of government, industry, and universities in three diffusion-related areas of opportunity:

* Technology transfer and research cooperation, particularly involving small and mid-sized companies;

* Building upon state and regional technology initiatives; and

* Mutually beneficial international cooperation in science and technology.

Although scholars describe these kinds of policies as "diffusion--oriented," the term "capability-enhancing" is perhaps more descriptive. Such policies are not so much distributive in their objectives as they are aimed at enhanced power to absorb and employ technologies productively.[84] Capability-enhancing policies are designed to prepare workers for an increasingly sophisticated work environment and develop their problem--solving abilities, to accelerate the commercialization of innovative ideas, to increase the productivity and lower the cost of industrial production, and to

[84] Skeptics of "diffusion-oriented" policy sometimes associate "diffusion" with active policies to transfer information assets from the haves to the have-nots. This is, of course, not how diffusion works, either in molecules or in information. Information diffusion is a random process in which receptors may filter what they need from that which is flowing freely in the public domain. Technology transfer, on the other hand, usually represents a transaction between identified parties, in which information flows unidirectionally between them.

increase the capacity of all firms, large and small, to use technology to improve their competitiveness. The net effect of a capability-enhancing policy is to diffuse economic benefits and increase competition not by "picking winners" but by increasing innovative capacity.

Although demand-side technology policy has a long and honored history in agriculture, new tools and techniques brought to farmers by agricultural extension agents, making U.S. agriculture the most productive in the world, the dominant U.S. STI policy has been a supply-side policy. Contemporary political accommodation to the idea of a more demand-side "technology policy" began with President Reagan's reorganization of the Commerce Department and acceptance of the 1988 Omnibus Trade and Competitiveness Act (Public Law 100-418). The technology policies established by this act were designed primarily by Senator Ernest Hollings of South Carolina, but they were widely supported by both Republicans and Democrats in the Congress.

The Act gave a new name, the National Institute for Standards and Technology (NIST), and a new mission to the venerable National Bureau of Standards. NIST's new mission includes three programs, all viewed with some suspicion by economic conservatives: the Advanced Technology Program to finance "pre-competitive generic" research in commercial firms; an experimental technology-extension program to help smaller manufacturers improve their productivity; and the establishment of manufacturing technology centers in cooperation with the states.[85] White House skepticism, however, has restricted these three NIST programs to less than three percent of DARPA's R&D budget, despite a generous congressional authorization. Thus the three Commerce programs must be regarded as very tentative experiments in capability-enhancing technology policy.

Fig.2
Policies For Technology Diffusion

(Access, adaptation, use, and sharing of technology)

Systematic acquisition, dissemination of foreign technology.
Evaluation, adaptation, and dissemination of technical information in the U.S.
Technical services and industrial extension.
Investments in human resources (education, school-to-work, worker training).
Collaborative technical activities among firms.

[85] *Strategic View,* Technology Administration, U.S. Department of Commerce, (Washington DC: U.S. Department of Commerce, Technology Administration, November 1991.)

a. Information Infrastructure

Public investment in information infrastructure, however, has several advantages over investments in prescriptive megaprojects and technology transfer programs that target specific industries. Infrastructure investment does not predetermine the relative emphasis to be given to any particular sector, whether it be manufacturing, agriculture, resource extraction or services. Information infrastructure allows information flows to follow demand, rather than requiring demand to be predicted. In that sense information infrastructure is enabling.

The Internet, and its proposed successor, the National Research and Education Network (NREN),[86] are examples of "information infrastructure.[87]" It incorporates both public and private components, emphasizes the diffusion of useful knowledge, and contributes to both vertical and horizontal integration of intellectual and economic activity. Its structure and pricing policies can explicitly provide for equity in access to services by subsidizing academic connectivity. To the extent that it embodies new technology (for example, the gigabit backbone network) NREN anticipates new applications.[88] By testing such technologies in a research network, NREN will lower the economic risk of their introduction into commercial service.

Optimal utility of a new service is determined by the experience of users.[89] New information services respond to application innovations (such as telecollaboration, distant learning, vertical integration, and consensus management) without requiring government decision-makers to understand the pace of change brought on by information technology. Much of the technology transfer promoted by government policy today specifies the relationships it seeks to promote, forcing information flows into

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[86] Executive Office of the President, Office of Science and Technology Policy, *The Federal High Performance Computing Program,* Sept. 8, 1989. For a convenient summary see U.S. Congress, Office of Technology Assessment, *High Performance Computing and Networking for Science -- Background Paper,* OTA-BP-CIT-59 (Washington DC: U.S. Government Printing Office, Sept. 1989).

[87] The following definition of "information infrastructure" is used in this discussion: "Information infrastructure is comprised of those facilities and services whose shared use by individuals and institutions, both public and private, enable more efficient and effective creation, adaptation and diffusion of useful information."

[88] Richard and Paulette Mandelbaum, "The Strategic Future of the Mid-level Networks," *Building Information Infrastructure: Issues in the Development of the National Research and Education Network,* ed., Brian Kahin, (New York, McGraw-Hill, 1992).

[89] The ARPANET was originally conceived as a means for load balancing mainframe computers, taking advantage of the four U.S. time zones. Users quickly discovered the attractions of electronic mail, file transfers among remote collaborators, and other applications.

prescribed and sometimes inappropriate channels. It is in this sense that NREN services are considered "enabling."

Cross-subsidization is common in the publicly supported component of infrastructure, reflecting government concern for equity as well as efficiency and efforts to compensate for market imperfections. Elements of infrastructure may be public (such as libraries) or private (such as communications carriers) or mixed (e.g., NSFNET). They may be capital intensive (e.g., NSF supercomputer centers) or labor intensive (e.g., the U.S. Postal Service). They may be subsidized (as are university research laboratories), private but not-for-profit (such as ANS[90]) or profit-driven (e.g., Meade Data Central's Lexis/Nexis service). Finding the correct balance of public and private investment and of user charges to ensure the cooperative interplay of such diverse activities is a major challenge for public policy.

Because an essential characteristic of infrastructure is its accessibility, standards also are important issues of public policy. Standards usually evolve through a publicly accountable process. In the case of NREN three sets of standards must be harmonized: the Federal Communications Commission's telecommunications standards for the carriers, the Office of Management and Budget's Federal Information Processing Standards (FIPS) for the government run services, and the American National Standards Institute (ANSI) voluntary standards for commercial components and services.

Information infrastructure depends equally on "hard" and "soft" technologies, both, that is, on the physical network and on the arrangements for locating, adapting, acquiring, and using information supported by software and manual services. Government regulations, or at least policies, must seek to coordinate these hard and soft technologies, so that access and connectivity are enhanced throughout the information infrastructure.

These issues are made more important and more complex by the rapid shift from paper and voice access to government generated information to electronic distribution through digital networks. Electronic information searching can be both more selective and more comprehensive than with paper; it can certainly enjoy superior economies of scale. Importantly, on-line systems permit user feedback, which, if correctly used by those managing the information collection, organization, and quality, can increase dramatically its value to users. This capacity, however, raises its own issues -- how to preserve the privacy of information users while making information services more responsive to their needs.

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[90] ANS is the Advanced Network and Services Co., a not-for-profit joint venture of IBM and MCI Corporations which, working for Merit, Inc., provides the backbone NSFNET service for the Internet.

The government's investment in the National Research and Education Network (NREN), a central part of the strategy to develop the nation's information infrastructure, will make expanded STI services accessible to thousands of laboratories in universities, industry, and government. By aggregating a national market for such services, it can attract investment by private information vendors as well as justify increased government efforts in STI. Agencies should now be planning investments in the data collection, evaluation, user adaptation, and search strategies needed to support the rising demand for information services over the network.

The Internet is widely connected internationally, and provides a vital link between professionals in smaller or less developed countries and the much larger number of scientists and engineers in the larger, wealthier countries. This is a welcome fact in most quarters of government; indeed government agency sponsored networks form the core of the Internet and many of them are international in character.

The fact that the NREN legislation is based on the goal of improved economic performance in the U.S. means, however, that some politicians may question whether the openness of Internet to foreign participation is consistent with the goal of giving Americans a comparative advantage in international competition. This concern arises primarily in the case of Japan, whose science strength is far weaker than its industrial practice. There is danger, however, that political efforts to put constraints on the unimpeded flow of information on the Internet might be made. Such an attempt I would call "intellectual protectionism." Brazil practiced a reverse form of such protectionism some years ago with its constraints on digit traffic across the border, but these constraints have been substantially removed. This is an area where some international agreements might be merited.

b. Industrial Extension Services

The provision of technical advice to small businesses to improve their economic performance is of course familiar in the field of agriculture. From the time of the Morrill Act of 1862, establishing the land-grant colleges for "agricultural sciences and the mechanical arts" the federal and state governments have collaborated to provide technical extension services to farmers. These services also provided for the subsidized diffusion of research knowledge coming from both federal and state agricultural research stations. This process has been extraordinarily successful; only two percent of the population is required to feed the other 98 percent, plus a significant part of the rest of the world.

The analogous service to small manufacturers and other businesses has had much less acceptance and less success, in part because farms produce commodities with little product differentiation within a crop, and the industry is very highly fragmented. When the state helps one farmer reduce his costs and increase his earnings, there is little discernable economic effect on the price his neighbor receives or the demand for his product. Furthermore, the information farmers require has been of a largely generic nature, applicable to a great many of them. Industrial extension services must be much more specifically adapted to the applications of each firm.

In the late 1960's the Congress passed the State Technical Services Act, to provide industrial extension services; after a modest beginning, federal funding ceased and little remains of this effort. In the 1980's the states began to take initiatives on their own. By 1988 44 of the 50 states were investing annually some $ 550 million in efforts to promote innovation. Only about 10 percent of this goes to industrial extension, however.[91] A 1990 National Governor's Association survey estimates that only 11,800 of the 355,000 U.S. small and medium sized manufacturers (which produce half of U.S. manufacturing value added) were helped in any demonstrable way by extension services.[92]

The Omnibus Trade and Competitiveness Act of 1988 assigned to the National Institute for Standards and Technology (NIST -- formerly called the National Bureau of Standards) responsibility for establishing in collaboration with states or groups of states as series of Manufacturing Technology Centers, seven of which are in operation or in the process of establishment. The Act also authorized establishment of an industrial extension program with the states, although the Bush Administration did not request more than token funding for this activity. The purpose of the Manufacturing Technology Centers (MTCs) is to bring modern production technology to small and medium sized manufacturers. In effect NIST has combined the functions of the two programs, linking the MTCs to state based extension services. An important focus is on the use of programmable machine tools and automation. But increasingly the Centers services are being broadened to cover technical management issues such as total quality management and the European quality process standard ISO 9000.

The Clinton-Gore technology policy document notes that in Germany the Fraunhofer Gesellshaft operates some 40 contract R&D centers and uses industry cooperatives to diffuse the technology across industry. In Japan there are 170 "Kohsetsushi" technology support centers for small business, funded at $ 500 million per year. The Clinton campaign proposed creating 130 U.S. centers to engage in extension services. The details of this plan are not yet clear. It seems likely that what will emerge is a set of perhaps 30 Manufacturing Technology Centers placed in strategic locations around the U.S., each specializing in production tools and processes common to the region. These MTCs would be linked by computer network to perhaps 100 Manufacturing Outreach Centers "MOCs" - much smaller offices with a few extension agents providing "retail" services to small business in their

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[91] Megan Jones, "Helping States Help Themselves," *Issues in Science and Technology*, vol. 6, no. 1 (Fall 1989.) see also Philip Shapira, *Modernizing Manufacturing: New Policies to Build Industrial Extension Services* (Washington DC: Economic Policy Institute, 1990).

[92] John Lyons, director of NIST, private communication.

locale. It seems clear that the advice and help they can provide must be in the basic business services area as well as in technology and production.

Whether such an ambitious program will be created is problematic for at least three reasons:

> * It depends on matching funds from the states, most of which have considerable difficulty sustaining discretionary expenditures of this kind through good times and bad;
>
> * There are questions about the extent to which such services should be fully self-sustaining financially, since the firms assisted should be able to appropriate all the benefits. In most states only the first visit is free; in some there are recapture clauses in the agreement;
>
> * There are questions about competition between public services and those from profit seeking consultants, although most state programs operate at the entry level of services, where fees are too low to be of interest to professional consulting firms.

If such a national program of extension services is to be created, it will require a high level of cooperation among the states, since all will be sharing the specialize resources accessible through the network. If that obstacle is overcome it may have another benefit. Today the state governments compete with one another to attract job-creating investments, either from direct foreign investment or from U.S. firms considering relocation. This competition often takes the form of subsidies, either through donated land, tax abatement, or other benefits. The result is that astute firms force state governments to bid against each other, resulting in tax subsidies to firms without any evident benefit to the American nation as a whole. If the states could agree to collaborate in a positive-sum economic game, all would be better off.

6. The Universities: A New Social Contract?

Section 1.c. described the social contract that expresses the surprisingly stable U.S. science policy since World War II, and the stresses it is now encountering. Congressman George Brown, Chairman of the House Committee on Science, Space, and Technology knows more about science policy and the functioning of the American technical enterprise than anyone else in Congress. He is a strong supporter of science and has earned the right to point out the vulnerabilities to which the old policy paradigms are now subject. His September 8, 1992 Los Angeles Times editorial sets the text. His position is clearly stated: unless the academic scientific community abandons its tenacious claim to autonomy in resource allocation and performer selection as a matter of entitlement rather than a means to serve American interests, even the best friends of fundamental research will feel they cannot, in good conscience, increase academic science budgets when they compete with urgent social priorities.

The same theme runs through the Task Force report issued Sept. 15 by Cong. Boucher's subcommittee outlining a project for the committee to challenge the effectiveness with which OSTP allocates research resources to agency activities and ensures that the resulting knowledge and technology flow in a timely manner to public benefit.

In September 1992, Dr. James Duderstadt, Chairman of the National Science Board, and Dr. Walter Massey, director of the National Science Foundation, chartered a Commission on the Future of the National Science Foundation. Its report to the National Science Board was submitted in early December 1992. The fear that the social contract is already being renegotiated -- unilaterally -- made many academics and professional societies feel threatened by the very existence of the Commission.

The Commission's recommendations, however, struck a middle ground. It made four points:

> * The NSB should not remain passive while enormous changes are taking place in the U.S. science and technology enterprise, its policies, institutions, and goals. Many of the mechanisms through which science creates public benefits are beyond NSF's control. Many are managed by federal agencies other than NSF. NSF has two choices: take on the entire technological food chain from research to market, or take an active, indeed leading, role in helping the President and his Assistant for S&T formulate a technology policy within which NSF's proper role is defined and linked to the rest of the S&T and innovation enterprise. The first course leads to disaster, the second fulfills NSB's legislative mandate.
>
> * The NSF should continue to support research in the sciences and in engineering, and provide the facilities and infrastructure required for a strong national research capability. The present portfolio of disciplines and activities is broad enough; NSF does not need to expand that portfolio. The problem lies more in maldistribution of funds in relation to technical needs, not the need to add still more kinds of functions to NSF. Nor should NSF allow its engineering centers or its investments in NREN to be divested to some civilian technology agency (as proposed in one transition document). NSF's grants should continue to insist on intellectual excellence in all it does, foster unsolicited proposals, cherish its "bottoms up" style of project choice, and cling to merit based competitive performer selection.
>
> * NSF must recognize that the U.S. technical community is weaker than it should be in many fields that are quite exciting intellectually but also could make a very big contribution to the nation's technological comparative advantage. An example is synthetic polymer chemistry. NSF must not allow pressure from disciplinary constituencies to prevent a distribution of resources into it's programs and activities that better matches the technical challenges facing America. Instead it should reach out to technically sophisticated people who understand the fields in which American science and engineering are underinvesting, and ask them to participate in an improved resource allocation process that is better matched to national needs

than today's programs reflect. This is a job for NSB itself. It should pay more attention to disciplines and interdisciplinary research known to be poorly represented in our universities as we shift our attention from cold war to a cold economy. More advice from the most technically qualified people with industry experience should be sought. NSF should not tell university scientists what to do; it need only put properly allocated resources in the paths of bright people.

* NSF must take more seriously the effectiveness of linkages that connect academic science and engineering to the users of the knowledge created, and strengthen those linkages where possible, even as we recognize that those linkages are quite extensive already. (See section 4.c.iv.) The object is not to force university scientists to "get in bed" with industry (NSB should do that) but to ensure that academic researchers have multiple opportunities to benefit from and collaborate with colleagues in industry and others putting science to use. Among appropriate linkage mechanisms, in addition to students going to work in industry, are university centers with industry participation, faculty-industry exchanges, development of the NREN and facilities shared with industry users, support for data evaluation, reviews, and S&T information services, workshops, conferences, and travel.

The academic science community is in danger of being isolated politically on this issue, since there are very large segments of the science community -- mostly in federal and national laboratories and some in industry -- that have already made their peace with working in a more utilitarian environment where need-driven priorities drive resource allocations even for basic research and where linkages to the processes of research utilization are accepted as an integral part of the research plan. Note that $20.8 billions are spent on R&D in the federal laboratory system (including FFRDCs) while only $20.4 billion are spent on R&D in universities (see section 4.c.ii.). If the new social contract is tied to greater assurance that public benefits will flow from science and the mechanisms for flow are made explicit, it still isn't clear

* how the "negotiation" takes place, or

* what a new "social contract" would look like.

On the first point, the scientific community has little bargaining power; it is going to have to accept what gets served up. Its influence is limited to blaming the politicians for being the instruments of destruction of a public asset. This is likely to get press but produce little in the way of good outcomes. The real negotiation is within the political process dealing with alternative strategies for defining the role of government-funded science -- indeed the role of any government activity -- in achieving the socio-political agenda being defined now in the election campaign: jobs, environment, security, infrastructure, and fiscal stability. The new negotiation is taking place between conflicting constituencies on these issues. Scientists are on the sidelines. If that is the correct view of the "renegotiation" process, then the right preposition is "social contract for science" not "with science."

On the second point, the political structure of federal policy toward science is, and will be, heavily influenced by factors that have essentially nothing to do with the philosophical elements of relations between government and science. For example, the earmarking of more than $ 700 million of the FY 1992 budget for academic facilities and research has nothing much to do with alternative views of how science diffuses in the economy; it is a power play serving local political interests. Earmarking is a symptom of the fracturing of the current social contract, since it is clear that commitment to autonomy for science is insufficient to prevent the earmarking. The same thing can be said for the other pieces of evidence for the crumbling of the social contract: public alarm over accusations of scientific misconduct, over mishandling of research overhead accounting, over university insensitivity to the loss of American technical advantage through foreign guest scientists and engineers in our best universities.

Underneath all of this evidence that all is not well in the view of academic science held by the public, the media and the politicians, are three other factors which are putting pressure on resources for academic science:

> * The recognized fact that having the most Nobel Laureates has not protected us from a loss of competitive advantage in important areas of industrial technology.[93]
>
> * The pressure on academic science budgets coming from the fading of support from Defense and the deficit-driven budget squeeze. As government policy shifts from a mission-oriented strategy (that relies on spinoff from defense and space and trickle-down from basic science), the universities are likely to suffer, along with industry.
>
> * A growing appreciation, around the world, that under the right incentive structure (with market incentives first but not alone on the list) the private sector does a better job of execution of tasks for society than do big bureaucracies. This push for privatization also tends to cast doubts on the efficacy of federal research investments.

How might a new "social contract" come about, providing another several decades of stable support for academic science and engineering? When one tries to think about what a new social contract might look like, it is not difficult to describe possible new policies. Some of these policies are already

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[93] No one in a position of responsibility ever said it would. But too many spokespersons for science have deliberately fostered the impression that strong science (along with strong defense and space technology would indeed assure a strong economy. These chickens have now come home to roost.

identifiable in the Bush Administration National Technology Policy of Sept. 26, 1990 and in Clinton-Gore issue statements. But it is less clear how these policies emerge as elements of a bargain based on a negotiation with each "side" conceding some authority to the other in exchange for some benefit that retains some authority.[94] Until this issue of finding a new and stable basis for supporting NSF's mission in academic science is successfully addressed, many conflicting expectations will continue to plague NSF, plague the political community, and plague the scientific community.

Universities are being torn by unreasonable expectations of their role in economic performance; to degree they have themselves to blame. They are also being torn between their commitment to global communities and their obligations as nationally chartered institutions, dependent on national sources of support. This is a special form of the economic policy issue every government must face: what criteria determine whether foreign owned domestic firms are eligible to participate in government funded incentives for improved economic performance. This is what Robert Reich has called the "Who's Us?" question.[95]

What charges arising from the growing importance of technological capability in international economic competition are being laid at the feet of university administrations?

* By hosting foreign researchers, especially those from foreign firms, and even by accepting endowments for professorships from foreign firms, universities are "giving away" knowledge assets paid for by American taxpayers without fair recompense.[96]

* By hosting one third of all the foreign students in the world, U.S. universities are engaged in a massive knowledge drain (despite the known fact that most of the best 60% of those students stay in the U.S. after graduation).

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[94] The process leading to the social contract in the Vannevar Bush era is more evident in hindsight. There were two clear protagonists in the 1944 - 1948 period. The protagonists were Senator Harley Kilgore (D-Tenn), Vannevar Bush, a Republican yankee industrialist heading OSRD in the Roosevelt and Truman administrations, Harry Truman and his staff (leading to his veto and creation of the National Science Foundation. During this time the National Academy of Sciences was an active (and conservative) influence in the negotiation. In the current discussion the NAS is still a conservative voice, but the technical community is far more diverse than before and speaks with many voices, including the voice of academic engineering, largely unheard 40 years ago.

[95] Reich, Robert, "Who's Us?" *Harvard Business Review*, Jan.-Feb. 1990, p. 53

[96] This concern was raised in Congressional hearings by the late congressman Weiss of New York. More recently, legislation was introduced (and subsequently blocked) to forbid unclassified basic research funded by NSF and NIH from reaching foreign firms -- an idea that is at one and the same time impractical and frightening.

* By publishing everything they learn in open literature they are favoring foreign firms that are able to commercialize new ideas more quickly than American firms. The inference is that the U.S. government should invest less in fundamental research; the alternative of course is for U.S. firms to accelerate their ability to acquire, adapt and exploit new knowledge from all sources.

* By insisting on scientific autonomy -- researching those problems interesting to disciplinary academics rather than problems of greater interest to U.S. industry, universities are diverting scarce government resources to disciplines of low economic value.

* By working primarily within established disciplines and by strong preference for individual faculty investigator support, academics are preventing interdisciplinary research by teams of investigators that would make more rapid progress toward technologies of economic value.

and finally,

* By cavalier management of indirect cost accounting and occasional lapses into scientific misconduct, universities are abrogating -- or at least endangering -- the social contract under which scientific autonomy was assured for the last forty years.

My conclusion is that universities will have to walk a very delicate line between expecting recognition for the very real contribution they make to the technological roots of economic performance in this country, and the commitment to truth and scholarship without regard to national boundaries that is prerequisite to their intellectual integrity. Striking that balance successfully is much more important, I suggest, than wiring all the buildings with optical fibers and putting a computer on every desk. The ultimate solution requires that our society discover that its self interest lies in a global market of ideas as well as of goods, and the universities represent our eyes and ears, learning from as well as teaching others.

7. Changing S&T Roles for the Defense Department

As noted in section 1.d.i., the sweeping changes in the U.S. national security situation are causing upheavals of substantial magnitude in the Department of Defense and the nuclear program in the Department of Energy. But Defense was having substantial difficulty selecting, procuring, and managing the technology on which it depends even before the breakup of the Soviet Union and its alliances.[97] The challenge of strengthening the defense industrial base at time of rapidly declining resources is very great, and clearly requires a fundamental restructuring of the defense acquisition system.

a. Dual Use Technologies

As noted in section 1.b. above, defense technology is increasingly dependent on sources of technology in highly competitive, global, high tech industry. The potential for synergy between defense and commercial applications of technical knowledge centers on the concept of "dual use" technology. "Dual use technology" does not mean a technology that has two uses. It means a technology that has an indeterminate number of potential uses, at least some of which are of significant military importance and some are of material non-military importance.

Thus technologies for designing, making and using jet engines, optical fiber cable, magnetrons, boron fiber composites, rocket propellants, infrared sensors, ion implanters, computers, 3-D hydrodynamic codes, and automated turret lathes are all "dual use technologies." They could, as easily, and perhaps with more accuracy be called "multiple use" technologies.

Some dual use technology is so general in its application that it can support virtually all of the technically sophisticated applications of specialized military equipments and high-function commercial needs. Perhaps the best example is jet engine lubricants, where military and commercial standards are essentially identical world-wide. Another example is optical fibre communications cable or high speed bipolar circuits (although some military adaptation is needed to reduce sensitivity of these circuits to nuclear and E-M radiation.)

The "ultimate" example of dual-use technical knowledge comes from basic scientific research. Both defense and commercial technologies grow from the same seeds of scientific knowledge, benefit from similar tools, techniques, processes and materials, draw on the same system of education for scientists, engineers and mathematicians.

b. Defense-Commercial Relationships

It is noteworthy that the Administration and Congress are no longer looking to the Defense Department to provide policy cover for experiments in direct civilian technology support.[98] Defense

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[97] Carnegie Commission, *New Thinking and American Defense Technology*, (New York, Carnegie Commission on Science Technology and Govennnment) August 1990.

[98] Dr. Radford Byerly, Staff Director for the House Science, Space, and Technology Committee, noted during the Colloquium that since the Congress failed to repeal the prohibition against transferring budget allocation from defense to domestic civil programs this year, Congress

has its hands full downsizing its program and adjusting to new and lower budget levels. Thus the era when Defense was used as a cover for a "surrogate industrial policy" may be drawing to a close. But the new role for Defense R&D and its relationship to the commercial sector remains undefined. *Beyond Spinoff* calls for a radical change in Defense acquisition policy which requires building bridges between defense agencies such as DARPA and commercial firms.[99] The purpose of these bridges is not to accelerate the flow of military technology to the commercial sector, but to give the Defense Department access to the nation's best technology, which increasingly resides in the commercial divisions of American manufacturers.

A task force of the Carnegie Commission on Science, Technology, and Government chaired by Admiral Bobby Inman, called for changes in DARPA which would confirm DARPA's practice of investing in dual-use technologies and go further by encouraging DARPA to collaborate with civilian agencies concerned with the same technologies and undertake cooperative agreements with commercial firms for dual-use technology development. These new relationships would be recognized by renaming the agency National Advanced Research Projects Agency, or NARPA. Senator Jeff Bingaman has introduced a bill implementing this recommendation: *The National Advanced Research Projects Agency Act of 1992.* As I said in my testimony to the Joint Economic Committee last September,

> "DARPA and the rest of the Defense Department is going to have to realize that the United States now lives in a world of technology, most of which is private, a large part of which is not even located in the United States. Defense is going to have to use it."[100]

The Clinton-Gore technology policy paper contains a commitment to "review and eliminate barriers to the integration of our defense and civilian industrial base."

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might be tempted to relocate civil programs within defense programs. The motive, however, would not be to draw the mantle of national security over projects some might claim were "industrial policy."

[99] John Alic, Lewis Branscomb, Harvey Brooks, Ashton Carter, and Gerald Epstein, *Beyond Spinoff: Military and Commercial Technologies in a Changing World*, (Boston: Harvard Business School Press, April 1992).

[100] Lewis M. Branscomb, testimony to the Joint Economic Committee of the Congress, Sept. 12, 1991. Also quoted by Sen. Bingaman in his statement in Congress on April 2, 1992.

8. International Issues in S&T

a. Technology and Trade Relations

Every one of the four changes described in section 2 entails increased international dependencies for the U.S. The breakup of the super-power stalemate creates a multipolar world where international relations are less constrained and offer increased opportunities and challenges. Security affairs will have increased political content and will be more regional in character. Competition in the world economy, with the rise of Asia and Europe as major economic powers, means that the U.S. will more frequently require the financial as well as political collaboration of other powers, as proved necessary in the Gulf War. International affairs in science and technology can be expected to become more multi-dimensional, less polarized by the Cold War and more responsive to regional situations and relationships.

If the 1992 U.S. election campaign is a predictor of President Clinton's priorities, his focus will be on the domestic economy. Despite this, President Clinton world view is fundamentally internationalist. As befits the post-Cold War era he will understand that relations with trading partners such as Mexico and Brazil desire a high priority. The effectiveness of this focus on international affairs will be limited, unfortunately, not only by his domestic priorities, but by the weakened S&T capabilities of the Department of State.

A recent comprehensive study of science and technology in U.S. international affairs finds the U.S. government poorly placed to deal effectively with S&T issues in their foreign policy context.[101] The commission found "a crazy-quilt of poorly defined responsibilities, inconsistent strategies, and inadequate resources, frequently knotted up and occasionally knitted together by *ad hoc* mechanisms of coordination."[102] The corps of science counselors in U.S. embassies around the world is outnumbered 3:1 by the S&T officers of foreign embassies and consulates in the U.S. alone.[103] Government agencies and U.S. firms alike too often fail to search out and utilize technology from around the world. This will change, but the change may come slowly.

A second trend is a consequence of the increased codification of science and engineering, described in section 2.d.iii. The codified (theory based) parts of science and engineering, a rapidly growing fraction of technical knowledge, moves around the world with the speed of electrical signals. Together with the strengthening of technical and business relationships among manufacturers who

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[101] *ibid.* page 45,46.

[102] *ibid.* p. 11.

[103] Carnegie Commission, *Science and Technology in U.S. International Affairs,* (New York: Carnegie Commission on Science, Technology and Government) Jan. 1992.

supply each other, firms are distributing their operations geographically. The Asian NICs have taken strong advantage of this trend. It may be of increasing importance to Brazil as well, especially if its economy can be stabilized. This is leading governments to move beyond science as the basis for bilateral cooperation to embrace cooperative projects in technology as well.

The economies of the newly industrialized and, indeed, of many still developing countries have been growing more rapidly than the economies of the highly industrialized democracies, and accordingly offer the major market growth opportunities for the U.S. This should lead to an enhancement of S&T relations, which have for so many years been hostage to the cold war. Competition for these markets is helping stimulate a number of international projects in science and engineering in the fields of basic science, of environment, and of industrial development. An example of the latter is the Intelligent Manufacturing Systems project, the idea of Prof. Yoshikawa of Tokyo University and put forward internationally by MITI. It is aimed at developing new manufacturing systems technologies that offer increased productivity, flexibility, and product quality. The manufacturing technology initiative started by the Bush administration, which will almost certainly continue, and the industrial extension services the Clinton administration is pledged to expand provide a platform for technology cooperation with Brazil and other nations.

U.S. exports have been growing faster than the domestic economy for some years. Concerns about labor displacement by imports have been high on the political agenda of the Democratic Party. U.S. trade policy, however, has so far resisted the temptations of more extreme forms of protectionism. The North American Free Trade Agreement seems reasonably assured of enactment. The NAFTA may have some short term negative impacts on Brazil, if Mexico moves into agricultural and other products for which Brazil enjoys export trade to the U.S.

Aside from the NAFTA, however, U.S. attention is fixed on Japan -- because of the huge U.S.-Japan trade deficit -- and the European Community, because of signs that community integration may come at the cost of external non-tariff barriers. President Clinton's acceptance of the NAFTA and his early meeting with the President of Mexico, even before he took office, does suggest the possibility of extending more open trade throughout Latin and South America. In any case the economic liberalization already achieved in Brazil should be met with more forthcoming trade policies in the U.S.

b. Science and the Bilateral S&T Agreement

The U.S.- Brazil bilateral Science and Technology agreement has been in effect since 1971. It was renegotiated last year, but is being held up pending resolution of differences over handling of intellectual property, to be resolved in an exchange of letters. The U.S. side is optimistic about a solution, but passage of intellectual property legislation in the Brazilian Congress has encountered an enormous number of amendments and at this writing is unresolved.

Opportunities for S&T bilateral cooperation are expanding as a result of the globalization of science, referred to above, even though Brazil's universities and publicly supported research institutions have been hard pressed as a result of the budgetary crisis in the government. The area of manufacturing technology, where the Japanese have taken the IMS initiative and many industrialized nations, including the U.S. participate is one example. Another is the environment, where U.S.A.I.D. has projects in 90 countries at a level of more than $ 400 million per year. Projects concerning forest fires, for example, have been underway with Brazil. The U.S. Global Climate Change Program is budgeted at over $ 1 Billion per year, and includes a major investment in data analysis and distribution. The Earth Observations Satellite Data Information System (EOSDIS), initially a NASA system for handling the huge volumes of data from satellite instrumentation, is being seen as a network whose reach is international with researchers and policy analysts in other nations invited to participate.

In the field of basic science the costs of major facilities -- telescopes, space craft, oceanographic vessels, high energy physics accelerators, and the like -- has so outrun the resources of single nations that there are strong pressures to internationalize their planning, finance, and management. Even the U.S. is no longer able to build the world's leading facilities at its own expense and offer them to visiting scientists from around the world as had been the case in the past. This lesson is being learned painfully in the case of the Superconducting Supercollider project (SSC). This high energy physics project was originally intended to be funded by the U.S. and other nations were not invited to participate in its design and planning. When the costs rose to some $ 8 billions, the U.S. approached Japan and other nations, asking for cost sharing. This request has effectively been rebuffed.

It was noted above that the U.S. Department of State has not accorded a high priority to science and technology matters in recent years. It is also true that the U.S. has been a difficult partner in international cooperative projects. As the Carnegie Commission on Science, Technology, and Government put it, "The United States must work to improve its reputation as a reliable partner in international environmental efforts...."[104] There are two primary problems: annual appropriations which put continuation of financial commitments at risk and the lack of a coherent policy toward international scientific cooperation.[105]

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[104] Carnegie Commission on Science, Technology and Government, *Environmental Research and Development: Strengthening the Federal Infrastructure*, (New York: Carnegie Commission) Dec. 1992, page 96.

[105] Alexander Keynan, "The United States as a Partner in Scientific and Technological Cooperation: Some Perspectives from Across the Atlantic," Consultant report to the Carnegie Commission on Science, Technology and Government, June 1991.

c. Informatics and Intellectual Property Rights

Information policy has emerged again as a major element of federal policy toward science and technology. The U.S. played a leadership role in the OECD in information policy in the early 1970s.[106] But shortly thereafter informatics lost its place on the policy agenda, and efforts that had been led by the White House were pushed down to agencies, which received little encouragement. This trend has been reversed, in large measure because of the power of computer networks to create markets for information services, to enhance communications and collaboration, and to allow the sharing of scarce resources, specifically the federally sponsored "supercomputer" centers.

An important international S&T facility is the Internet, now a global computer network facilitating remote access to sources of technical knowledge and facilitating remote collaboration. Internet is the largest collection of interconnected networks in the world -- a collection of over 4000 networks among which electronic mail messages flow. In 1992 107 countries were connected directly or indirectly to the Internet.[107] Anthony Rutkowski estimates that at least 10 million people have access to the Internet world wide, and the traffic level in 1992 was growing at over 10 percent per month. In the U.S. some 28 million personal computers, or 56% of all PCs installed in the US, will be attached to others through local area networks (LANs) by the end of 1995.[108] Many if not most can be expected to be attached to the Internet. The spread of networks around the world can accelerate developing country access to the world's knowledge resources. At the same time, because the information infrastructure of many developing countries is often weak, their ability to take advantage of the global networks is limited.

In December 1991 the Congress passed the High Performance Computing and Communications Act, which authorizes the evolution of the Internet into a broadband, switched network connection many networks together and serving the needs of education and research. This is the NREN, the National Research and Education Network.[109]

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[106] L.M. Branscomb, Pierre Piganiol, S. Balke, S. Hamada, H.T. Hookway, and J.R. Whitehead, *Information for a Changing Society: some policy considerations*, OECD, Paris 1971.

[107] Larry Landweber, "International Connectivity", *Internet Society News*, Vol 1 no.1 Jan. 1992, page 3.

[108] Forrester Research's *Network Strategy Report: LANs for Free?* Nov. 1991.

[109] Lewis M. Branscomb, "Information Infrastructure: A Public Policy Perspective," in Brian Kahin, Ed., *Building Information Infrastructure: Issues in the Development of the National Research and Education Network*, New York: McGraw Hill, December, 1991.

Senator Albert Gore, Jr., was the champion for this legislation. Having been elected Vice President, he is almost certain to continue to give information technology in general and NREN in particular a high priority in the administration.

Information technology brings certain unique policy issues into play, most especially issues concerning intellectual property. The U.S. position on intellectual property has been to press for reciprocal treatment in every country that enjoys I.P. rights in the U.S. This issue is increasingly a source of friction between north and south. It is likely to continue to be a source of friction because of the growing importance of I.P. in the informatics and service industries, world wide. In addition, there are pressures on the U.S. to move away from its "first to invent" patent system, and internal concerns about the awkward fit of computer software to either patent law or copyright.[110]

d. Global and Domestic Environment Issues

The election of Albert Gore, Jr. as Vice President clearly portends a major shift in U.S. policy on the environment. President Clinton's fiscal conservatism will limit the public funds that can be invested in measures to reduce the rate of injection into the atmosphere of greenhouse gases and to find accommodation with the developing nations for global sustainable development. Where President Bush held back on support for the UNCED in Rio De Janiero, and attended the Rio conference only briefly, Senator Gore was present and active in his support of the conference goals.

President Clinton has delegated to the Vice President responsibility for science and technology policy coordination. V.P. Gore will certainly include environment in that scope, for he hand-picked both the Administrator of the EPA (a former staff member to Senator Gore and more recently director of the Florida EPA), as well as the science advisor. As noted above, Global Change research will continue to receive strong government support in the U.S., and the Global Change Data and Information System is being designed to encourage other nations to participate in it, using the international services of the Internet.

Shifts in environment policy can be discerned of four kinds:

> * President Bush's "no regrets" policy on global climate change rested on the assumption that no action would be take to reduce carbon consumption unless it was justified by other necessities, such as oil import reduction or air pollution. thus if global warming proved to be

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[110] Computer Science and Telecommunications Board, National Research Council, Intellectual Property Issues in Software, Washington DC: National Academy Press, 1991, pp. 111. (L.M. Branscomb chaired this study team and workshop.)

illusory, there would be "no regrets" over costs needlessly incurred reducing greenhouse gases. The Clinton-Gore administration is more likely to seek a middle course, with early steps to reduce atmospheric CO_2 production, through an oil import tax or a gasoline tax, or both.

* Transnational and global environmental impacts are becoming a much larger part of the international affairs agenda in governments rich and poor. With the election of Clinton and Gore it is likely that the U.S. government will take a much more activist position than the Reagan and Bush administrations have done, as evidenced by the U.S. positions at the Rio Conference.

* Most large manufacturing firms face major environmental costs and risks, and no longer treat environment as simply a public relations and regulatory issue; it has become a part of mainstream business strategy. This is leading to technical efforts to modify industrial processes to minimize those risks and costs, and to pressures on government to modify the regulatory regime to encourage this process approach, instead of focusing regulations on technologies to remove pollutants from process outputs.

* Government is beginning to experiment with market surrogate mechanisms, such as tradable permits for emitting pollutants, in order to improve both the incentives on industry and the efficiency of the regulatory process. The 1991 Clean Air Act includes such provisions. This policy direction provides enhanced incentives for private efforts; its advocates believe it will lower costs of meeting environmental goals. The U.S. will probably urge other nations to follow this policy direction.

* Political leaders are beginning to react to Japanese and German government actions to promote the development of "green" production technologies and equipment as a strategy for building an environment export market to reduced domestic economic cost of environmental compliance. Similar R&D investments by government may be seen in the U.S. in the future. The possibility of sharing such "green" technologies with developing countries as part of an overall north-south accommodation on global climate change and other transborder environmental effects will doubtless be discussed as such programs develop.

In summary: the new administration will be much more willing to discuss constraints on greenhouse gas emissions in international venues than was President Bush, but President Clinton's fiscal conservatism and commitment to reduce the federal deficit will not allow a major concessional assistance program to the South in return for constraints on goal and wood burning or deforestation.

e. Energy and Non-proliferation

The Department of Energy will continue to be absorbed in environmental remediation of its nuclear facilities, for which total cost of over $ 100 billion is estimated over a period of years. With the political transformation of the former Soviet Union, the rising number of nations apparently seeking a nuclear weapons capability, and a dramatic rise in regional conflicts, non-proliferation will be high on the administration agenda and will color its attitude toward nuclear fuels and reprocessing. Brazil experience serious friction with the Carter administration over this issue, but the return of Democrats to power does not signal a similar level of policy conflict with Brazil, if Brazil ratifies the agreement to accept the IAEA safeguards signed by Brazil and Argentina in December 1991.

A second concern will be the downsizing of its nuclear weapons establishment, as noted in the section on national laboratories. This second effort will, however, give the department incentives to look for energy-related technology activities. The Energy Department will be pushing hard for alternative fuels for automobiles, but will probably be more skeptical of the virtues of ethanol than was the Bush administration. It is likely that a gasoline tax will be levied, to bring revenue to the treasury and provide incentive for conservation. The administration will also press forward with their project to develop a practical battery for powering electric or hybrid gasoline-electric cars. Given Brazil's extensive experience with ethanol-powered vehicles, and at the same time Brazil's new source of hydroelectric power, a cooperative U.S.- Brazil project evaluating the prospects for both electric and alternative hydrocarbon fueled cars might be attractive to both countries.

9. "Megaprojects" and technology demonstrations.

One of the conspicuous failures of government management, which might be alleviated with the right process of evaluation, is the technical "mega-project." Linda Cohen and Roger Noll have studied six cases of such projects, each intended to accelerate the commercialization of a capital intensive technology.[111] Among their cases were the supersonic transport aircraft, the Clinch River breeder reactor, a coal gasification project, and the solar photovoltaic program. In each case a nominally attractive economic case was in hand at the beginning of the project, but the project was soon captured by constituencies that lobbied for it and benefitted from it. When either the market or the technology changed, the political environment prevented the project from adapting to new circumstances. As they became conspicuously uneconomic political justifications were invoked and kept most of the projects alive long after any utility remained.

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[111] Linda R. Cohen and Roger G. Noll, *The Technology Pork Barrel*, (Washington DC: The Brookings Institution, 1991.)

The normal program planning, review, and resource allocation process is not sufficiently robust to contain such projects within sound limits. What is needed is a requirement, embodied in the authorizing legislation, that the economic and market assumptions on which such projects are based are rendered explicit, and that the goals and the implementation plans be exposed to external as well as internal analysis and review. This external evaluation should be repeated at defined intervals, and the process and its conclusions made public. What institutional structure might perform such reviews? One solution is to charter the National Academy of Engineering to create a panel for each project, funded to subcontract the analytical work to professionally qualified institutions. The final decisions would be made in government, presumably in the OMB, of course, but the fact that the evaluation is external to government will protect the evaluation from the political conflict of interest inherent in the administration's responsibility for managing it.

10. Science Advice and S&T Decision Making

a. "Taxonomy" of U.S. science advisory functions, activities, and institutions.

At least ten kinds of government functions are supported by formal institutional structures for the provision of outside scientific and technical advice. See Table 4:

Table 4.
"Taxonomy" of U.S. science advisory functions,

Advisory Function	Example
High level policy: setting political agendas.	PCAST: advises President
Technology assessment: socio-technical agendas.	OTA: advises Congress
Regulatory processes: statutory advisory committees.	RAC: advises the FDA
Procurement strategies, resource allocation.	Peer review panels
Program management: tracking specific programs.	IVHS America: advises Dept. Transportation
Policy analysis: support for executive agencies	NRC: advises all agencies
Policy support: program evaluation, planning.	DSB: advises Sec Defense
Institutional performance: evaluation committees for laboratories and other institutions.	NRC Review Panels for NIST
Part time governing boards, limited decision authority	NSB: governs NSF
One off commissions for special topics	President's Commission on Productivity

i. The Executive Branch

At the highest levels of government there are boards of citizen-experts who provide general policy advice, in addition to considering specific issues put to them by government officials. President Bush met regularly with his President's Council of Advisors on Science and Technology (PCAST). This distinguished group of scientists and engineers, drawn from both academic and business experience, was led by the President's Assistant for Science and Technology and represents the apex of science advice to the executive branch of government. The PCAST is not required by statute, however, and there is no certainty that President-elect Clinton will appoint such an advisory body. The scientific community will apply pressure to have him do so. This high level advisory committee both legitimates the Administration's actions in science policy, and legitimates the President's Science Advisor in the eyes of the scientific community.[112]

Most of the executive departments also have high level boards of science and technology advisers and a myriad of more specialized advisory committees throughout their agencies. The Defense Science Board gives both solicited and unsolicited advice to the Office of the Secretary of Defense. The statute establishing the National Institute for Standards and Technology (NIST) requires the appointment of a Statutory Advisory Committee to assess this agency's performance and to call to the attention of the Secretary of Commerce any policy issues that concern the committee members.[113]

Federal regulatory agencies setting mandatory limits or providing product approvals to protect the environment and public health and safety also have a variety of advisory bodies, some statutory, to review proposed agency regulations and to advise on agency research, processes and technical assessments.[114] An explosion of new agencies, each with associated advisory mechanisms, occurred in the early 1970s. EPA was established in 1970. It created a Science Advisory Board in 1974, which was given statutory permanence in 1978. The 1977 Clean Air Act amendments required establishment of the Clean Air Scientific Advisory Committee to review the science underlying proposed standards. In 1975 a Science Advisory Panel was created to review proposed pesticide regulations. A similar array of advisory bodies sprang up in the Food and Drug Administration (FDA), the Department of Agriculture, and in many other regulatory agencies.

ii. The Congress

The Congress has its own institutions for providing scientific and technological early warning and advice. Best known is the Office of Technology Assessment (OTA) whose studies are commissioned by bipartisan agreement of Congressional committees. Science and technology policy advice is also provided by the Library of Congress' Congressional Research Service (CRS) and the General

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[112] William Golden, ed., *Science and Technology Advice to the President, Congress, and Judiciary*, (New York: Pergamon Press), 1988; William Golden, ed., *Science Advice to the President,* (New York: Pergamon Press), 1980.

[113] This committee, chaired by Mervin J. Kelly, President of Bell Telephone Laboratories, played a critical role in the resolution of a bitter controversy over the handling of the "Battery Additive AD-X2" case in 1953. U.S. Congressional House Committee on Science and Technology, 96:1, "Technical Information for Congress," (Washington DC: July 1979) Government Printing Office, pp. 23-69.

[114] Shiela Jasanoff, *The fifth branch: Science Advisors as Policymakers* (Cambridge MA: Harvard University Press, 1990.)

Accounting Office (GAO). The Science Policy Division of the CRS provides quick response to Congressional requests, and the GAO's studies stem primarily from its responsibility to audit the executive agencies' stewardship of their Congressional authority. The OTA is notable among advisory bodies in the federal government in that it engages in studies in considerable depth, often requiring a year or more to complete, and conducted under a bi-partisan charter. While its reports cannot be said to be free of political content, they provide analysis of alternative policies rather than making actionable recommendations. The primary source of Congressional advice on science and technology is, of course, invited testimony from both experts and advocates in public hearings conducted by the committees and in studies commissioned directly by the Congress. There is no institution in the executive branch comparable to the OTA.

Enhancing the ability of Congress to deal more effectively with the scientific and technological content of the issues before it is a quite different matter from addressing the problem in the executive branch. The Congressional process has been addressed by two studies made by the Carnegie Commission on Science, Technology, and Government[115] under the leadership of John Brademas, which recommended the formation of a Congressional Study Group on Science and Technology, through which more effective ways to deal with scientifically complex issues might be explored.

iii. The Quasi-governmental Sector: National Academies of Science and Engineering

Perhaps the most impressive (in scale, variety, and level of expertise) source of advice for federal agencies and the Congress is the National Research Council (NRC), Congressionally chartered in 1918 at the request of President Woodrow Wilson to provide expert advice to the federal government on matters of science and technology. The NRC is managed by the National Academy of Sciences (and its sister bodies the National Academy of Engineering and the Institute of Medicine), which itself was chartered to advise the government in 1863.[116] In response to agency and Congressional requests, the NRC performs studies engaging annually the volunteer services of 9,500 experts. On sixty occasions in the last five years the Congress has mandated NRC studies, resulting in

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[115] Carnegie Commission on Science, Technology, and Government, *Science, Technology, and Congress*, in two parts: *Analysis and Advice from the Congressional Support Agencies,* October 1991, and *Expert Advice and the Decision-making Process,* (New York: Carnegie Commission, Feb. 1991.)

[116] The "Act to Incorporate the National Academy of Sciences" of March 3, 1863, specifies that the Academy "...shall, whenever called upon by any department of the government, investigate, examine, experiment, and report upon any subject of science or art...." It further provides for the expenses of such advice to be defrayed by the requesting agency, but provides that "...the Academy shall receive no compensation whatever for any services to the Government of the United States." Thus all members of advisory panels serve without compensation.

Congressional testimony on 200 occasions during this period.[117] The NRC is certainly the single most active source of outside advice to the government on scientific matters, and it comes closest to representing the technocratic approach, in which as far as possible scientists give advice devoid of conclusions as to the political implications of its conclusions. However, the NRC panels have become more astute about understanding the political context of their work. The result, however, is that many NRC studies frustrate the Congress' desire to come to grips with the political issues.

b. Shortcomings and Suggestions for Institutional Improvements.

> A. High level science and technology perspectives are inadequately present in policy determinations where the issues are not seen as primarily technical.
>
> B. High level science and technology advice to the executive branch does not effectively address long term issues of broad technical scope, especially when the government's objectives are not clear nor strongly publicly supported.
>
> C. Advice on sustaining the vitality of the U.S. science and engineering enterprise becomes suspect when it comes from self-serving advisory bodies addressing the needs of their own community.
>
> D. The utility of science and technology advice requires that expert advisers achieve technical and political legitimacy, which, in turn, legitimates the functions of the government bureaucracy. In a democracy the legitimacy of "experts" is always subject to question.
>
> E. How can science and technology advice contribute to informed and rational self-government in a world of increasing technical complexity? How, in fact, is legitimacy to be achieved? This is a question that must be explored if we are to understand the role of science advice in the U.S. political system.

We must look to the nature of the American version of the modern democratic state, which not only requires access to expert knowledge for conducting the affairs of government, but requires a sufficient degree of legitimacy for the decisions of government to justify the continued delegation of power from the electorate. In this respect the nature of American politics seems to be very different from that of many other democratic states, especially as it regards the behavior of politicians and the roles of elites.

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[117] This information was provided by Dr. Philip M. Smith, Executive Officer of the NRC Governing Board, Feb. 7, 1992.

Yaron Ezrahi[118] advances the thesis that the Founders of the new American nation saw science as a cultural model which validates the idea that witnessing the instrumental exercise of public responsibilities satisfies the normative goals of the citizenry. Ezrahi emphasizes the empirical, practical, experimental approach we normally associate with American culture. Because Americans reject the delegation of authority to a self-selected elite to make decisions on complex matters in our behalf, he argues, they insist on judging officials by their actions. Science becomes the paradigm for the source of public knowledge and order, and of authority legitimated by informed, voluntary consent. Thus science is used to depoliticize politics.

> "The physicians, physicists, chemists, engineers, economists, psychologists, and other professionals who are massively deployed at all levels of government action in the modern democratic state help institutional instrumentalism not only as a substantive mode of action but perhaps even more as a political strategy for constructing, legitimating, and criticizing public action."[119]

The deficiencies of provisions for incorporating the advice of technical experts into the formulation of public policy in the U.S. have much more to do with process than with organizational structure. The key problem is the accommodation of the cultures of science and of politics in ways that preserve the values inherent in their differences as well as dealing with their interdependence. Even more fundamental is the nature of the public institutions for conducting the public's business and the quality and motivations of the managers and politicians in charge. No institutional mechanism for advising a President can overcome the President's disinterest; no President desirous of independent advice on a scientific matter will have difficulty satisfying his need. But well constructed and managed advisory bodies can not only help the nation take advantage of the knowledge available to its citizens, but can help empower those citizens to hold their public representatives accountable and strengthen democracy.

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[118] Yaron Ezrahi, *The descent of Icarus: Science and the Transformation of Contemporary Democracy*. (Cambridge: Harvard Univ. Press, 1990).

[119] Ezrahi, *loc. cit.* page 38.

11. Indirect policies

This paper has focused on federal activities in generation and diffusion of technology through support of technical operations. There are also indirect policies to enhance technical performance of the private sector. Most proposals for indirect policy fall into the sphere of macroeconomics: efforts to reduce the cost of capital, to induce investment in plant and equipment through investment tax credits, to create equity capital through reduction in long term capital gains, and to encourage increased R&D investment through R&D tax credits. All of these policies have the effect of aggravating an already serious federal deficit, which limits their attractiveness as tools for dealing with industrial competitiveness. The direct policies have two advantages: most are targeted to activities selected for their effectiveness, and most can be funded by shifts in investment from defense to non-defense purposes.

Both President Bush and Governor Clinton endorsed making permanent the incremental R&D tax credit. Congress has been extended this tax credit year by year, and proponents of making the credit permanent argue that uncertainty about future tax benefits deprives this tax credit of much of its power to motivate increased R&D investment.

12. The Clinton-Gore Technology Policy: Current Issues

The Clinton-Gore campaign paper on technology policy promises to renew the civilian technology base, shifting the balance between defense and non-defense federal R&D from 60:40 to 50:50. The policy paper features six broad initiatives:

> "1. Investing in 21st century infrastructure [including a digital, broadband communication system called the Information Network System];
>
> 2. Establishing education and training programs for a high-skills work force;
>
> 3. Investing in technology programs that empower America's small businesses;
>
> 4. Refocusing federal R&D programs on critical technologies that enhance industrial performance;
>
> 5. Leveraging the national R&D investment; and

6. Creating a world-class business environment for private sector investment and innovation."[120]

A significant decision by President-elect Clinton is to entrust to the Vice President, Albert Gore, Jr., "the responsibility and authority to coordinate the Administration's vision for technology and lead all government agencies, including research groups, in aligning with that vision." the statement goes on to say,

> "The Vice President will take on the task of organizing all facets of government to develop and implement my Administration's technology policy. As a first step, he will establish a central focus for the coordination of government activities related to civilian technology and create a forum for systematic private sector input into U.S. government deliberations about technology policy and competitiveness."[121]

On reading this statement, it is unclear what the role of OSTP is intended to be, for by law it is the "central focus for the coordination of government activities in ... technology." It is unclear, as of early January 1993, whether technology will be more visible on the White House agenda, with the Vice President assuring that S&T issues reach the President's attention, or whether the effect will be to isolate technology as a political issue in the Vice President's Office, weaken OSTP, and reduce the effective access to the President of the Director of OSTP (who serves also as Assistant to the President for Science and Technology.) One favorable early sign is that for the first time in sixteen years the incoming president has nominated his science advisor prior to inauguration. Dr. John Gibbons, Director of the Congressional Office of Technology Assessment and a nuclear physicist with a strong environmental background, has been named for this post. His credentials as a policy analyst for science and technology issues is unchallenged.

13. Current Issues and Conclusions.

It is likely that the emphasis on **lists** of critical technologies is a transient event in U.S. technology policy, although the language is surely here to stay. If new policies are to be implemented, they must be clearly stated, with objective criteria for project selection and evaluation, and related to stated goals. On the other hand, so long as governments go beyond basic research in attempts to provide a knowledge environment supportive of a competitive, expanding economy, they will have to define policies that:

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[120] *Technology: The Engine of Economic Growth: A National Technology Policy for America*, (Little Rock, Arkansas: Clinton-Gore National Campaign Headquarters, Sept. 21, 1992)

[121] Clinton-Gore *loc. cit.*, page 8.

* differentiate the government's role from that of private investors and entrepreneurs, and

* set priorities for government investments in civilian technology.

The idea that programs meriting priority will be called "critical," will sooner or later have to give way to the reality that the government's role is not defined by "criticality" but by the under-investment by private firms in knowledge with large positive externalities. Just as one would not call government funding of basic research in low temperature physics "critical" to national well-being, the association of "critical" with "generic" will become increasingly inappropriate.

Signs that the policy debate is becoming more sophisticated are at hand. The American Technology and Competitiveness Act of 1992, sent forward to the House of Representatives by the Committee on Science, Space, and Technology in the summer of 1992[122] has a title III entitled Critical Technologies. It focuses, however, not on the identification of "critical technologies" but on mechanisms to coordinate the development of a national policy, the implementation of which will ensure United States leadership in technologies (and their applications) ...essential for industrial productivity, economic growth, and national security..."

The work on priority setting for federal R&D, already launched by the Subcommittee on Research of the House Committee on Science, Space, and Technology, will see the development of clearer, more appropriate language in this area. The need for competitive and comparative assessment of U.S. industrial technology is clear. The distinction between the use of export controls and export promotion should reduce the danger of confusion. Finally, the need to focus on the appropriateness of federal expenditures, and not just on priorities for choosing technical areas should become apparent.

Perhaps the best explanation for the emergence of critical technology studies is the recognition that government missions have defined technology priorities in the past, and a new way to set priorities in support of economic health must be evolved. Critical technologies -- as a concept without policy relevant criteria -- is not up to the task.

There are five primary obstacles to consensus on technology policy as it relates to the civil economy:

(a) lack of crisp, robust criteria to delimit the federal role in each of the program types devoted to commercial technology;

[122] H.R. 5231.

(b) concern that the discipline of such criteria will be corrupted politically, the primary reason many conservatives oppose an active technology policy;[123]

(c) lack of confidence in the ability to build government institutions with the competence and the latitude to make judgements -- a view that deprives agencies of legitimacy;

(d) confusion about direct foreign investment and how to deal with U.S. firms that are subsidiaries of foreign corporations, and the overseas subsidiaries of U.S. headquartered firms;

(e) lack of strong constituency for the kind of decentralized program of technical investment that has difficulty competing with the concentrated spending of megaprojects.

One obstacle to consensus on technology policy is the question most often posed by economists: What proof have you that U.S. industry is in technological decline, requiring government intervention? This is coupled with a question asked by conservatives, including many business people: What proof have you that the government has the competence to help, even if such help were indicated?

To the first question: It does not matter. In fact, there are many signs of resurgence of U.S. manufacturing competitiveness. Even the merchant semiconductor industry has reversed its loss of world market share, and is showing a small gain. The U.S. government should be helping to enhance the comparative advantage of its institutions and people either way. Indeed, it is more likely that government R&D will be useful if industry is optimistic and is investing for the future, than if it is cutting costs, reducing R&D and laying off people.

To the second question: Strategic technological assistance to save a hard-pressed segment of industry will usually face a poor prognosis. But the U.S. government has demonstrated for forty years the ability to create basic science for the world, and technology for its own missions, through the very kind of decentralized, merit-based, competitive programs that are needed for pathbreaking and infrastructural technologies. It need only update its conception of public goods, to include those two categories of technology, and develop the required cooperation from the technical expert in industry to help manage the new programs.

There remains this question: What constituency will support the emerging technology policies and shield the politicians from the heat of criticism when conflicts arise, as surely they will?

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[123] Murray Wiedenbaum, testimony before the Joint Economic Committee of the Congress, Sept. 12, 1991.

Only the business community, supported by labor and the technical community, can provide legitimacy and effectiveness to technology policy. Business leaders must articulate the economic and political philosophy that allows a role for government in the encouragement of path breaking and infrastructural technologies. If they do, political leaders will follow their lead. Here one must be impressed by the consistent support for a well constructed federal program of investment with the private sector in technology infrastructure. The National Association of Manufacturers, the Council on Competitiveness, the Computer Systems Policy Project and trade groups such as the American Electronics Association and the Aerospace Industries Association are consistent in their call for a more methodical and managed effort to enhance the technical comparative advantage of U.S. firms.

How might government be organized to carry out such a policy? The most obvious assignments are as follows:

Fig. 3
Restructuring Government for U.S. Technology Policy

* State governments: federalism in economic/technology policy.
  Operational initiative in diffusion policy.
  Abate destructive competition for foreign investment.
  Consensus on treatment of foreign ownership.

* Commerce Department lead agency role for civil technology.
  Build constituency and industrially experienced leadership.
  Recreate advisory structure for private sector input.
  NIST as primary operating agency for civil technology policy.

* New roles for Defense and DOE weapons laboratories.
  Rebuild acquisition policies and regulations.
  Re-emphasize long-range R&D role.
  Down-size where missions are shrinking.

* New roles for Energy and Environment Departments.
  Energy Department has vast R&D resources, shrinking mission.
  EPA is a regulatory agency; environment needs technology development and environmental science associated with regulatory function.
  Suggests combining into new Department of Energy and Environment.

* Need for coherent policy development and management in the Executive Office of the President.

OSTP-CEA-NSC supported by FCCSET and the Critical Technologies Institute.[124]
The critical near term question is the role of the Vice President.

I draw six conclusions:

(a) Even as nations experiment with new paradigms for industrial policy, the relationship of science to engineering and the ways science and engineering are used by industrial competitors are changing rapidly.

(b) Public policies for enhancing the technological dimensions of competitiveness, and the assumptions underlying these policies, have quite different histories and different priorities in Europe, North America, and East Asia.

(c) These policies are still evolving in all three regions of developed industrial economies, but are beginning to come together as all industrialized nations face similar challenges and opportunities.

(d) The trend is increasingly toward private initiative and private resources, in industrialized, former socialist, and developing economies, reducing the direct influence of governments.

(e) The new policies will call for much more sophisticated capabilities in government, and the economic health of the world will, paradoxically, depend even more on wise government policies, even as government action becomes more limited in scope and more restrained in nature.

(f) The primary challenge will not be the relationship of government and private efforts within each of the three industrialized areas, but the need to preserve an open environment for economic and technological alliances across area boundaries and to bring other economies, especially the newly-developing and former socialist countries into this vibrant world community of cooperating and competing nations.

In conclusion: with the election of Gov. Clinton as President, the nation has endorsed placing priority on domestic economic concerns. Initially this will probably have the effect of drawing attention away

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[124] OSTP: Office of Science and Technology Policy; CEA: Council of Economic Advisors; NSC: National Security Council; FCCSET: Federal Coordinating Council for Science, Engineering, and Technology.

from the international dimensions of science and technology policy. However, the previous administration's foreign policy focus was not on trade, science cooperation, and other relationships with U.S. trading partners in the hemisphere. It was clearly focused on the USSR and the attempt to neutralize Soviet influence around the world. Today the U.S. is in a state of rapid policy change, as indeed Brazil may be. This rate of change will soon begin to slow, and the U.S. government will have the opportunity for innovation in the field of foreign relations. Given the strong international interdependence of science and technology, and the important place that foreign trade plays in the economies of both countries, it is likely that the climate will quickly improve for stronger U.S.-Brazilian relationships.

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