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TECHNOLOGY POLICY AND CRITICAL TECHNOLOGIES

A SUMMARY OF RECENT REPORTS

By

Mary Ellen Mogee

Discussion Paper Number 3

December 1991

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APR 25 '92

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THE MANUFACTURING FORUM

The Manufacturing Forum was conducted in 1990 and 1991 by the National Academy of Engineering and National Academy of Sciences to provide a means by which policymakers from government, industry, and universities could meet to discuss issues that influence the competitiveness of manufacturing industries. The Forum was based on the recognition that future challenges to the performance of U.S. manufacturing industries from increased foreign competition, from developments in new technology, and from changes in our domestic economic and societal climates can only be effectively met by a concerted effort on the part of industry, government, and academia.

The Manufacturing Forum was a device for improving communications among its members and to the larger community. It did not conduct studies, provide advice, or make recommendations on specific issues or policies.

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FOREWORD

The Manufacturing Forum has identified many issues that need to be addressed and many opportunities that need to be grasped on the way to improving the future performance and competitiveness of U.S. manufacturing industries, including changes in management practices, changes in the climate for investment, upgrading of the manufacturing workforce at all levels, and changes in a host of public policies intended to facilitate and/or constrain our manufacturing industries.

To facilitate its consideration of specific manufacturing issues, the Forum commissioned experts in a variety of fields to prepare discussion papers. Each author is encouraged to express his or her own views sufficiently sharply to catalyze serious discussion. The Forum members offer their individual views, which authors may accept or reject, but the papers do not in any sense represent the views of the Forum as a whole.

The relationship of U.S. technology policy to the health and future performance of U.S. manufacturing industries was a matter of broad interest to the members of the Forum. Technology policy is a relatively new domain of public policy concern, one that draws for its substance on a mix of issues and concepts from related areas including science policy, economic policy, trade policy, tax policy, regulatory policy, national security, and public administration. This mix has complicated the task of forging a consensus within the cognizant community regarding the proper domain of technology policy, and especially regarding the specific actions that need to be taken by government, industry, and academia in pursuit of an effective technology policy.

In recent years, however, a number of distinguished expert panels has examined U.S. technology policy and offered recommendations for change in light of the new international and domestic economic circumstances. Some convergence has been reached on the proper scope and content of a technology policy, although much remains unsettled. Of special interest is the emergence of generic precompetitive commercial and dual-use technologies as candidates for government support and the identification and analysis of specific "critical" technologies as a way to focus on top-priority substantive concerns.

To aid in its discussions of technology policy and critical technologies, the Manufacturing Forum commissioned Dr. Mary Ellen Mogee to summarize and evaluate the most important of the recent studies, including those that specifically address critical technologies. In addition to summarizing the prior work, she identifies areas of convergence and offers her views of the adequacy of this body of work and of needs for further inquiry and action.

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In addition to this paper, Dr. Mogee prepared a detailed compilation of the specific recommendations of each of the technology policy studies she reviewed. A limited number of copies of the compilation is available from the Manufacturing Forum upon request.

Ruben F. Mettler
Chairman

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Executive Summary

Two lines of activity have addressed concerns about the declining relative technological capability and competitiveness of the United States in the last several years. A series of reports and statements on U.S. technology policy has offered recommendations to enhance the performance of U.S. technology-based industries. Another series of reports has identified technologies which are believed to be critical for the future. This paper reviews more than a dozen of these reports and assesses the progress represented therein toward a national technology policy that supports U.S. industrial competitiveness. It also offers suggestions for steps that leaders in business, academe, and government might take to build on the reports

Evidence of progress in several respects may be found in the reports, including the policy enunciated by the Bush Administration of participating with industry in the development of generic, precompetitive technologies; the recognition of the need for participation by government, industry, academe, and labor; the consideration of the interrelationships between civilian and defense technology needs; and the identification of technologies that are critical to future economic competitiveness and national defense.

On the other hand, key issues remain unresolved. It is uncertain whether federal support for precompetitive, generic technology has enough political support to garner significant financial resources in the federal budget. There also appears to be opposition to using the critical technologies lists to reorder R&D funding priorities and in many cases the critical technologies are defined too broadly to be very useful for this purpose. Some reports call for leadership by the President of the United States, while others distrust the federal government and call for industry leadership.

The reports pay insufficient attention to certain important issues. They continue to focus on technology development, in contrast with technology diffusion and manufacturing modernization. They tend not to distinguish the different segments of U.S. industry nor recognize the difficulties in generalizing about the needs and interests of the U.S. industrial community. They leave key questions unanswered with respect to implementation of the recommendations.

The paper concludes that progress has been made toward a national policy for developing and applying technology as a source of competitive advantage, but much more remains to be done.

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Introduction

Events of the decade of the eighties brought home to the American public the importance of successful competition in global markets to maintaining national economic growth and standards of living. It was also difficult to escape the conclusion that technological advantage plays an important role in the competitive success of firms.

Many observers today are deeply concerned that the United States as a nation is not doing what is necessary to develop and use technological capabilities to sustain and build competitive advantage in global markets in the coming decades. There is an increasingly wide conviction that if present trends continue—if U.S. firms in key industries continue to lose world market share, and if U.S. technological capabilities continue to slip relative to those of other countries—the results will be slower national economic growth, fewer well-paying jobs, and a lower standard of living for future generations.

Two distinct lines of activity have addressed these concerns in the last several years. One is a series of reports and statements on U.S. technology policy which offer recommendations to enhance the performance of U.S. technology-based industries. The other is a series of reports that identify technologies which are widely believed to be critical for the future. These reports are the latest entrants in a 30-year public debate over the direction of U.S. technology policy.

The U.S. approach to technology policy historically has had two major dimensions. One dimension has consisted of policies intended to create a favorable climate for technological innovation, including macroeconomic policies such as tax incentives, as well as support for basic research and science and engineering education. The other major dimension has consisted of investments in research and development (R&D) related to specific federal missions. These investments have been heaviest in defense and space, but have also included such areas as agriculture, health, and energy. The private sector has been an important performer and beneficiary of the R&D performed in these areas.

Since the 1960s there have been warnings that the traditional U.S. technology policy has become inadequate. Many reports have been published recommending that the federal government adopt a policy for strengthening technological capability in the commercial sector more broad-

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ly. To mention just a few, these reports include the "Charpie" report of 1967,[1] the final report on the Carter Administration's Domestic Policy Review on Industrial Innovation,[2] and the National Academy of Engineering's 1988 report "The Technological Dimensions of International Competitiveness."[3] The author has reviewed many of the reports that were published in the 1960s and 1970s and documented the literally hundreds of policy recommendations that had been made up to that time for stimulating technological innovation and economic performance.[4]

Despite this proliferation of reports and exercises, U.S. technology policy has changed very little. Some legislation has been passed—for example, the National Science and Technology Policy Organization, and Priorities Act of 1976 (P.L. 94-282), the Stevenson-Wydler Technology Innovation Act of 1980 (P.L. 96-480), and the Research and Experimentation Tax Credit which was passed as part of the Economic Recovery Tax Act of 1981. However, important elements of the first two pieces of legislation were never implemented by the executive branch and the Research and Experimentation Tax Credit has never been made permanent. A variety of reasons have been postulated for this failure to respond, including the nature of the U.S. political system and the prevailing conservative political philosophy.[5]

Despite this history, conditions today may be riper than ever for obtaining significant policy change. U.S. world market shares and relative technological capabilities have continued to erode. Governments of most countries with which U.S. industry competes have acted to support technology-intensive industries regarded as strategic to their national economic interests. The fall of communism in many places around the world and the shift of technological leadership in many fields from the military to the civilian sector mean that national security may be linked more to economic challenges than to military threats.

All these changes increase the need for a broad national technology policy for developing and using technology to promote U.S. competitiveness. To achieve this goal would require many things: development of a broader consensus on the importance of development and use of technology to competitiveness, less rigid adherence to political philosophies that avoid government intervention in the market, acceptance by the federal government of new responsibilities, formulation of policy options that could effectively and efficiently stimulate technological innovation and diffusion (and improved analytical support for technology policy formulation), informed debate on technology policy options, consensual decisionmaking to adopt policies and establish programs, strong leadership at the highest levels of government, comprehensive and coordinated implementation of policies and programs, allocation of adequate resources, creation of new institutions or redirection of existing institutions, careful oversight and evaluation of programs, and sustained commitment to all of the above.

This paper assesses the progress made toward a national technology policy that supports U.S. industrial competitiveness. It does this by review-

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ing more than a dozen key recent reports on technology policy and critical technologies. It does not attempt to go beyond the reports to draw a more well-rounded or richer picture of the policy issues or extent of progress. Rather, drawing from the reports, it identifies areas where consensus has grown and areas where issues remain to be resolved.

The paper is organized in the following manner. The first two sections briefly summarize key reports on technology policy and critical technologies, respectively, describing their origins, purposes, and contents. The third section describes issues on which consensus has grown. The fourth section describes issues which remain unresolved. The fifth section presents some evaluative comments on the papers as a group, and the sixth section suggests next steps to build on the reports.

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Technology Policy Reports

One of the two main lines of activity in the latest round of public dialogue on U.S. technological capability and competitiveness has been a series of reports and statements prepared by prestigious groups on U.S. technology policy. The reports reviewed here are listed in Table 1. It is impossible to capture the full scope of each report. Instead, the paper describes briefly the group which prepared the report, the purpose of the report, and the nature of the recommendations made, as well as other noteworthy aspects of the report.

Some of these reports were prepared by federal government agencies—in both the executive and legislative branches—and federal advisory committees. Others were prepared by private sector groups, some representing industry, others consisting of industry, academe, and labor working together (See Table 1). This broad participation of key sectors of American society reflects the recognition that industry, government, academe, and labor all have important roles to play in formulating and implementing national technology policy.

In general, however, the reports address U.S. technology policy primarily in terms of government policies and programs. As can be seen in Table 2, which categorizes the types of recommendations made in the reports, most of the recommendations in these reports call for action by the federal government. Many of the reports refer, at least in passing, to the importance of the industrial role. Some make specific recommendations for action by industry and academia, but government action is their primary focus. Therefore, this report also focuses primarily on the recommendations of the reports for action by government.

OFFICE OF SCIENCE AND TECHNOLOGY POLICY TECHNOLOGY POLICY STATEMENT

Perhaps the most significant of the technology policy reports is the statement of the Bush Administration's technology policy, prepared by the White House Office of Science and Technology Policy (OSTP). *U.S. Technology Policy* is the first official statement of technology policy (as distinguished from science policy) issued by the Executive Office of the President.

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TABLE 1 Technology Policy and Critical Technologies Reports Reviewed for this Paper

Organization	Report
TECHNOLOGY POLICY REPORTS	
Carnegie Commission on Science, Technology, and Government	*New Thinking and American Defense Technology* (1990)
	Technology and Economic Performance: Organizing the Executive Branch for a Stronger National Technology Base (1991)
Council on Competitiveness	*Picking up the Pace: The Commercial Challenge to American Innovation* (1988)
	Gaining New Ground: Technology Priorities for America's Future (1991)
National Advisory Committee on Semiconductors	*A Strategic Industry at Risk* (1989)
	Capital Investment in Semiconductors: The Lifeblood of the U.S. Semiconductor Industry (nd)
National Association of Manufacturers	*Technology Policy Recommendations: Executive Summary* (1990)
Office of Science and Technology Policy, Executive Office of the President	*U.S. Technology Policy* (1990)
Economic Policy Institute	*Modernizing Manufacturing: New Policies to Build Industrial Extension Services* (1990)
U.S. Congress, Office of Technology Assessment	*Making Things Better: Competing in Manufacturing* (1990)
	Paying the Bill: Manufacturing and America's Trade Deficit (1988)
CRITICAL TECHNOLOGIES REPORTS	
Aerospace Industries Association	*Key Technologies for the 1990s: An Overview* (1987)
Computer Systems Policy Project	*Perspectives: Success Factors in Critical Technologies* (1990)
	Perspectives on U.S. Technology Policy, Part I: The Federal R&D Investment (1991)
	Perspectives on U.S. Technology Policy, Part II: Increasing Industry Involvement (1991)
U.S. Department of Commerce Technology Administration	*Emerging Technologies: A Survey of Technical and Economic Opportunities* (1990)
U.S. Department of Defense	*Critical Technologies Plan* (1989)
	Critical Technologies Plan (1990)
U.S. National Critical Technologies Panel	*Report of the National Critical Technologies Panel* (1991)

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TABLE 2 Categories of Technology Policy Recommendations

Technology Leadership and Modernization
- Government R&D
- Government technology acquisition
- Government technology deployment
- Government support of critical generic technologies
- Federal laboratories and commercialization of federally funded technology
- Technology infrastructure
- Industrial extension/economic development
- Standards
- Cooperation
- Using foreign technology

Financial Environment
- Fiscal policy
- Capital cost and patience
- Tax policy
- Incentives to save
- Leveraged buyouts and hostile takeovers

Harmonizing U.S Policies With Competitiveness Goals
- Antitrust
- Intellectual property rights
- Regulation
- Product liability
- Voice for competitiveness

Human Resources Environment
- Worker training
- Preschool
- Primary/secondary education
- Higher education
- Foreign students
- Using engineers better
- Multi-level

International Trade
- Unfair trade practices
- Export controls
- Trade-related intellectual property

S&T Policy Machinery
- White House advisory mechanisms
- Congress
- Coordination with States
- Commerce
- Defense

Leadership and Consensus

Private Sector Actions

Knowledge Base

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The policy statement discusses the role of the private sector in innovation and competitiveness and recommends a broad range of government policies to establish an environment conducive to these industrial activities. It breaks ground by acknowledging federal responsibility to "participate with the private sector in precompetitive research on generic, enabling technologies that have the potential to contribute to a broad range of government and commercial applications." In action terms, the new thrust is reflected chiefly in proposed funding for activities at the National Institute of Standards and Technology (NIST), including research on advanced manufacturing technologies and the Advanced Technology Program.

Whether the commitment to precompetitive research represents a significant policy change is debatable. At a minimum it represents an extension of the historical federal policy of close cooperation between government and industry in selected industries such as defense, aviation and space, agriculture, energy, and health care.

The key to the apparent change of policy lies in the terms **precompetitive** and **generic**. These terms were defined by Presidential Science and Technology Advisor D. Allan Bromley in a recent address:

- "A **generic technology** is simply one that has the potential to be applied to a wide variety of products and processes extending across many industries. A generic technology is typically not something that is sold commercially. Rather, it requires subsequent research and development, generally by the private sector, to result in commercial application."

- "**Precompetitive** refers to a particular part of the innovation process. It applies to activities before the point at which a company can tell whether a specific technology has commercial potential. It would not apply, for example, to the development of application-specific commercial prototypes."[6]

Supporting generic technologies is consistent with economists' arguments that the government has a legitimate role in areas of economic activity where there are market failures. Advances in generic technologies give rise to extensive positive externalities affecting many other industries beyond the one in which the advances originate by contributing to a broad range of commercial and government applications. Supporting generic technologies spreads the return on the government's investment and reduces the danger of government decisionmaking being dominated by special interests. Similarly, the appeal of limiting support to precompetitive R&D is that it avoids getting the government involved in actual market competition.

Another notable feature of the Bush technology policy statement is that it includes not only elements that are inherently technological in nature, such as federal R&D funding and technology transfer, but also elements

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such as education and training and the creation of a legal and economic environment conducive to investment and competitiveness. This makes the policy responsive to concerns that improvements in the nation's business climate and in the scientific and technological infrastructure are necessary to facilitate commercial technology development and application.

OFFICE OF TECHNOLOGY ASSESSMENT REPORTS

The congressional Office of Technology Assessment (OTA) has prepared a series of reports on technology, innovation and U.S. trade. The first in the series, *Paying the Bill*, relates the stubbornly high U.S. trade deficits of the 1980s to weakness in American manufacturing and lags in technology, in addition to the macroeconomic policies which are more often cited as the cause. It further argues that some of the pain of the inevitable adjustment of trade flows can be alleviated by improving U.S. manufacturing productivity and quality.

The second in the series, *Making Things Better*, looks at the reasons for U.S. manufacturing weakness, and suggests corrective policies. The report makes specific recommendations that address issues in a broad range of areas—including the cost of capital, human resources, customer-supplier firm relationships, and the need to modernize U.S. manufacturing capability—again underscoring the complexity of the necessary supporting policy relationships and the need for policy initiatives in many areas.

NATIONAL ADVISORY COMMITTEE ON SEMICONDUCTORS REPORTS

A series of reports on technology policy has also been published by the National Advisory Committee on Semiconductors (NACS), a group of officials from companies and government agencies active in semiconductor research and technology, established by the Congress to devise a national semiconductor strategy. Unlike the previous two reports, the NACS reports focus on the problems faced by a single, albeit important, industry.

Recommendations in the first NACS annual report, A *Strategic Industry At Risk*, cover the range from government R&D funding (including support of commercial technologies), capital formation, and human resources, to trade policy.[7] Of these, the NACS attaches most importance to the "availability, cost, and patience of capital." A follow-up working paper, *Capital Investment in Semiconductors*, analyzes the capital formation recommendations in more detail.

The NACS report calls for industry leadership in reversing the deterioration of the U.S. semiconductor industry. It states that "the Nation must act now, with the industry itself taking the lead and government at all levels participating as a strong partner." Its recommendations, however, are aimed at government action.

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NATIONAL ASSOCIATION OF MANUFACTURERS REPORT

The National Association of Manufacturers (NAM) published *Technology Policy Recommendations* to "improve the ability of industry to flourish in the United States." The NAM's recommendations fall into three areas: industry-government relations, the federal laboratory system, and alternative means of support for technology development. Other areas such as fiscal, monetary, and education policies that are also relevant to technology capability are not addressed in the report because the NAM has separate, ongoing policy thrusts in those areas.

The NAM viewpoint is significant because NAM represents major U.S. manufacturing firms. This report is notable because it acknowledges that industrial success depends on a supportive government—"one that at a minimum nurtures an environment conducive to innovation."

The NAM report suggests that traditional U.S. industry-government relationships may need to be adjusted because of changes in the nature of international competition. In doing so, however, it cautions that technology policy should be distinguished from industrial policy:

> "This does not mean that existing paradigms should be discarded in favor of government-led industrial policies or 'technology-of-the-week' approaches. Rather, in light of anticipated international economic and competitive realities, alternate, industry-led means of promoting U.S. technological leadership in both defense and nondefense areas should be considered."

Several of its recommendations are aimed at industry—e.g., increasing interindustry cooperation and increasing industry cooperation with government.

Consistent with the traditional industrial viewpoint, the NAM report emphasizes the importance of a sound fiscal and monetary environment in promoting commercial technology. The report goes further, however, in supporting the Advanced Technology Program at the National Institute of Standards and Technology and in recommending government funding of even further "downstream" precompetitive development of enabling technologies when necessary.

COUNCIL ON COMPETITIVENESS REPORTS

The Council on Competitiveness—an organization devoted to improving U.S. competitiveness and comprised of executives from industry, organized labor, and higher education—has prepared two reports of direct relevance to technology policy. The first of these, *Picking Up the Pace*, focuses on the role of the federal government in facilitating and removing impediments to the commercial application of technology and makes recommendations for how the federal government can create an environment that is more conducive to the rapid commercialization of technology by the private sector. Its

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recommendations center on four areas: 1) macroeconomic policies, 2) science and technology policy-making machinery, 3) infrastructure, and 4) expanded national R&D efforts. Specific recommendations are made addressing key policy issues in each area.

Among its key recommendations *Picking Up the Pace* calls for appointment of an Assistant to the President for Science and Technology. (This was done in 1989 via the appointment of Dr. Allan Bromley to simultaneous positions as director of OSTP, presidential science adviser, and special assistant to the President.) Other recommendations address the issues of federal support for commercial application of technology, the legal and regulatory environment for the commercial application of technology, science and engineering education, the role of the federal laboratories, federal support for cooperative generic manufacturing technology, and DOD efforts to strengthen the U.S. industrial base.

Picking Up the Pace also notes that corporate management and government policymakers need to be guided by "a new understanding of the innovation process." It argues that adherence to the old research-driven, linear model of innovation, which has formed the basis for U.S. science policy since the end of World War II, has led to an overemphasis on research as the driver for technological innovation. This model has also reinforced a tendency to conduct research, development, manufacturing, and marketing in isolation from each other. The report offers an alternative model which describes innovation as a "reiterative, interdependent process in which design, manufacturing and product development all drive research and, at the same time, are highly dependent on research."

The second Council on Competitiveness report, *Gaining New Ground*, appraises current U.S. technology policy and concludes that current national policies and priorities do not adequately address the commercial technology challenge facing the United States. The report argues that the nation must redefine its goals to include a priority focus on technology that supports economic growth.

Gaining New Ground makes specific recommendations for action by government, industry, and academia, guided by the premise that government and the private sector must work together. Key recommendations for government action include a call for the President of the United States to make technological leadership a national priority and for federal and state governments to work together to strengthen the U.S. technology infrastructure. U.S. industry is called upon to establish more effective technology networks and to pursue best commercialization practices. Academia is challenged to develop closer ties to industry.

Gaining New Ground also argues that the United States should support core technologies that cut across many different sectors of the economy and drive U.S. industrial productivity and economic growth. The core technologies identified in the report are discussed in the next section on critical technologies.

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ECONOMIC POLICY INSTITUTE REPORT

The need to modernize manufacturing capabilities among small- and mid-sized U.S. firms is addressed in *Modernizing Manufacturing*, written by Philip Shapira and published by the Economic Policy Institute, an economic policy think tank. The report argues that a more effective industrial extension program would strengthen U.S. manufacturing capabilities; provide high-quality, cost-effective inputs to other manufacturers; and contribute to reducing the U.S. trade deficit. The report makes recommendations for actions the federal government could take to strengthen industrial extension programs. It also calls on the federal government to improve coordination with state governments in this area.

CARNEGIE COMMISSION REPORTS

The Carnegie Commission on Science, Technology, and Government—composed of individuals with broad experience in government and in science and technology—was established in April 1988 to assess the process by which the government incorporates scientific and technical knowledge into policy and decisionmaking. The Commission has published a series of reports, two of which are relevant to technology policy.

The earlier report, *New Thinking and American Defense Technology*, focuses on defense technology needs. It notes that political, economic, and technological changes around the world call for creative adaptation by government. These changes include the momentous political changes in the Soviet Union and Eastern Europe, the loss of American dominance over many fields of technology, and the Department of Defense's increasing difficulty in selecting, procuring, and managing the technology upon which it depends.

The report identifies adaptations in government organization and decisionmaking processes that would help fundamental readjustment to occur. It makes recommendations on providing high-level attention and oversight of science and technology issues in the White House and in the Department of Defense. It also makes recommendations on strengthening the defense technology base, stimulating the diffusion of high-leverage technologies from the laboratory to the field, stimulating the diffusion of dual-use technologies into industry, and increasing defense use of commercial technology.

The other report, *Technology and Economic Performance*, argues that in the future both economic performance and national defense will depend on commercially driven technology. The United States can no longer afford to have two technology bases—commercial and military—which are segregated from each other. Rather, the government must work deliberately to advance both civilian and military technology and create a truly *national* technology base.

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Although the report recognizes that the primary responsibility for commercial technology rests with private industry, it asserts that there is an important federal role in supporting generic technology, defined as technology that can contribute to a broad spectrum of uses. Toward this end the report recommends that the DOD and other federal agencies should have programs that enable their technology developments to serve commercial industry needs as well as military needs. One of the key recommendations is that the Defense Advanced Research Projects Agency (DARPA) be transformed into a National Advanced Research Projects Agency (NARPA) to provide stronger linkages between military needs and commercial industry.

Technology and Economic Performance also recommends changes in government organization and decisionmaking to improve the contributions of technology to economic performance. It argues that national technology investments must be driven by a "policy broader than simply the support of federal missions," one that "takes full account of the global nature of modern industrial technology." The report also argues that there is a need for a structure in the Executive Office of the President and the White House that can "develop and review federal programs and initiatives for advancing and diffusing technology and can assure consistent and timely policy and program decisions" and recommends new functions for OSTP and the National Security Council to achieve this. The report recommends that the President issue a directive defining federal responsibilities and roles in developing generic and precompetitive R&D to benefit U.S. economic performance.

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Critical Technologies Reports

The second recent line of activity with major implications for U.S. technology policy and competitiveness is a series of projects aimed at identifying critical technologies. The basic concept behind critical technologies is the need to focus attention and resources on important areas of technology.

With some exceptions, the reports do not address questions of what kinds of actions need to be taken by government or the private sector to ensure U.S. leadership and participation in the critical technologies. The identification of critical technologies in the reports, whether sponsored by government or the private sector, does not necessarily imply government action. Yet the reports may give this impression, because they generally stress the federal role and provide few, if any, details on the private sector role.

As noted in the previous section, the federal government has for years supported certain specific areas of commercial technology. These programs—exemplified by the Hatch Act of 1887 (which created the Agricultural Extension Service), the National Advisory Committee on Aeronautics founded in 1915, and more recently SEMATECH and the Manufacturing Technology Centers—have generally been ad hoc, narrowly focused, and isolated from broader national policies.[8] The current effort to identify critical technologies is to some extent an attempt to approach such governmental involvement in a more systematic manner—that is, to help set priorities among the many requests for government support for commercial technologies and to establish a framework for public and private sector actions.

Several lists of critical technologies have been compiled. Each represents an attempt at achieving agreement among an important set of players in national technology policy that a particular set of technologies is in some respect critical to the future of the United States. Some have been prepared by federal government agencies, others by private groups. Some focus on technology needs for U.S. industrial competitiveness, others on defense technology needs. Each group means something different by "critical" technology.

The critical technologies reports reviewed here are listed in Table 1. The reports' origin, focus, and criteria for selecting critical technologies are summarized. The critical technologies identified in each report are summarized in Table 3.

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TABLE 3 Comparison of Critical Technologies Lists

National Critical Technologies Panel[a]	COC Critical Technologies[b]	DOC Emerging Technologies[c]	1990 DOD Critical Technologies[d]	CSPP Critical Technologies[e]	AIA Key Technologies[f]
MATERIALS					
Materials synthesis and processing	Advanced structural materials	Advanced materials	Composite materials		Composite materials
Electronic & photonic materials	Materials processing	Advanced semiconductor devices	Semiconductor materials & microelectronic circuits		
	Electronic & photonic materials				
		Superconductors	Superconductivity		Superconductivity
Ceramics					
Composites					
High-performance metals & alloys					
MANUFACTURING					
Flexible computer integrated manufacturing	Design & engineering tools	Flexible computer-integrated manufacturing	Machine intelligence/ robotics	Manufacturing technology	Artificial intelligence
Intelligent processing equipment	Commercialization & production systems	Artificial intelligence		Integrated circuit fabrication equipment	
Micro- and nanofabrication	Process equipment				
Systems management technologies					
INFORMATION & COMMUNICATION					
Software	Software	High-performance computing	Software producibility	Software engineering	Software development
Microelectronics & optoelectronics	Microelectronics				

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TABLE 3 *Continued*

National Critical Technologies Panel[a]	COC Critical Technologies[b]	DOC Emerging Technologies[c]	1990 DOD Critical Technologies[d]	CSPP Critical Technologies[e]	AIA Key Technologies[f]
	Electronic controls	Advanced semiconductor devices	Semiconductor materials & microelectronic circuits	Microelectronics	Ultra-reliable electronic systems
	Optoelectronic components	Optoelectronics	Photonics	Optoelectronics	Optical information processing
	Electronic packaging & interconnections			Electronic packaging	
High-performance computing & networking	Computers	High-performance computing	Parallel computer architectures	Processor architecture	Computational science
	Database systems			Database systems	
				Operating systems	
				Applications technology	
High definition imaging & displays	Displays	Digital imaging technology	Data fusion	Displays	
	Hardcopy technology			Hardcopy technology	
Sensors & signal processing		Sensor technology	Data fusion		Advanced sensors
			Signal processing (includes phased arrays)		
			Passive sensors		
			Sensitive radars		
			Machine intelligence/ robotics		
Data storage & peripherals	Information storage	High-density data storage	Photonics	Storage (optical & magnetic)	
Computer simulation & modeling		High-performance computing	Simulation and modeling		
			Computational fluid dynamics		

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TABLE 3 *Continued*

National Critical Technologies Panel[a]	COC Critical Technologies[b]	DOC Emerging Technologies[c]	1990 DOD Critical Technologies[d]	CSPP Critical Technologies[e]	AIA Key Technologies[f]
	Human interface & visualization technologies			Human interface	
				Visualization	
	Networks & communications			Networks & communications	
	Portable telecommunications equipment & systems				
BIOTECHNOLOGY AND LIFE SCIENCES					
Applied molecular biology	Biotechnologies	Medical devices and diagnostics	Biotechnology materials & processes		
Medical technology		Biotechnology			
AERONAUTICS & SURFACE TRANSPORTATION					
Aeronautics	Propulsion		Air-breathing propulsion		Air-breathing propulsion
					Rocket propulsion
Surface transportation technologies	Powertrain				
ENERGY & ENVIRONMENT					
Energy technologies					
Pollution minimization, remediation, & waste management	Environmental technologies				

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TABLE 3 *Continued*

National Critical Technologies Panel[a]	COC Critical Technologies[b]	DOC Emerging Technologies[c]	1990 DOD Critical Technologies[d]	CSPP Critical Technologies[e]	AIA Key Technologies[f]
ALSO LISTED			Signature control		
			Pulsed power (includes high power microwaves)		
			Hypervelocity projectiles		
			High energy density materials		
			Weapon system environment		

Sources for Table 3:

[a]U.S. National Critical Technologies Panel, *Report of the National Critical Technologies Panel* (Washington, D.C.: U.S. Government Printing Office, March 1991)

[b]Council on Competitiveness, *Gaining New Ground: Technology Priorities for America's Future* (Washington, D.C., 1991)

[c]U.S. Department of Commerce, Technology Administration, *Emerging Technologies: A Survey of Technical and Economic Opportunities* (Washington, D.C.: Spring 1990)

[d]U.S. Department of Defense, *Critical Technologies Plan*, 1990 (Report to the Committees on Armed Services, U.S. Congress, 15 March 1990)

[e]Computer Systems Policy Project, *Perspectives: Success Factors in Critical Technologies* (Washington, D.C.: July 1990)

[f]Aerospace Industries Association, *Key Technologies for the 1990s: An Overview* (Washington, 1987)

NATIONAL CRITICAL TECHNOLOGIES PANEL REPORT

The 1991 *Report of the National Critical Technologies Panel*, a group consisting of 13 individuals with expertise in science and engineering chosen from the federal government and the private sector, is the first of a series of biennial reports required by Congress in the FY 1990 Defense Authorization Act. This report is widely viewed as a product of the Office of Science and Technology Policy (OSTP), because the Director of OSTP appointed nine of the panel members and the panel was chaired by an Associate Director of OSTP. A spokeswoman for the White House stated, however, that the report does not represent a Bush Administration position. A disclaimer that the views expressed were "solely those of the National Critical Technologies Panel" was also inserted into printed versions of the report.[9]

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The Panel's report emphasizes the importance of identifying technologies for concentration of effort, noting that technology development and deployment, because of the time and resources involved, require a greater selectivity and concentration of resources than does basic science. The purpose of the report is to highlight the importance of the critical technologies in meeting future national needs and to point out opportunities for public and private sector investments and actions.

The Panel report describes 22 technologies considered essential for the United States to develop for the Nation's long-term national security and economic prosperity. The criteria for selection of the technologies fall into three general categories:

National Needs
- Industrial Competitiveness
- National Defense
- Energy Security
- Quality of Life

Importance/Criticality
- Opportunity to Lead Market
- Performance/Quality/Productivity Improvement
- Leverage

Market Size/Diversity
- Vulnerability
- Enabling/Pervasive
- Size of Ultimate Market

The Panel report provides brief definitions of the criteria used in selecting the critical technologies. For example, the criterion "industrial competitiveness" is defined as "technologies that improve U.S. competitiveness in world markets through new product introduction and improvements in the cost, quality, and performance of existing products," and the criterion "vulnerability" is defined as when "potentially serious damage may be caused if a technology is held exclusively by other countries, and not the United States." Primary consideration was given to technologies that could be incorporated into commercial products or processes or defense systems within 10 to 15 years.

It is noteworthy that the panel did not focus explicitly on economic growth or promoting high-growth industries as a criterion. Also, it is clear that even with these criteria, difficult judgments were required and the resulting identification of critical technologies was inherently subjective and uncertain—a comment that applies as well to the other critical technologies reports.

The critical technologies identified by the Panel fall into six broad areas: materials, manufacturing, information and communications, biotechnology and life sciences, aeronautics and surface transportation, and energy

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and environment. Because there is much interdependence among the technologies—i.e., some technologies support or enable others—the Panel does not attempt to prioritize them. However, the Panel notes that the first three categories "form the basic 'building blocks' for virtually all sectors of the economy," whereas the last three categories are "major areas for technology applications."

DEPARTMENT OF DEFENSE CRITICAL TECHNOLOGIES PLANS

The Department of Defense (DOD) has prepared critical technologies plans in 1989 and in 1990 in response to the National Defense Authorization Act.[10] The intent of the requirement was to encourage the DOD to establish a planning process that would ensure that critical needs in defense technology development would be reflected in budget priorities.

The 1989 DOD plan identifies the 22 technologies that were considered most essential to develop in order to ensure the long-term qualitative superiority of U.S. weapons systems. They were chosen on the basis of whether they enhance performance of conventional weapons systems or provide new military capabilities, and whether they improve weapon systems availability, dependability, or affordability. Nuclear technologies are not included on the list. The technologies identified as critical by DOD (see Table 3) illustrate the broad scope of defense technology needs—from those derived from the general industrial base (e.g., microelectronics) to unique needs such as high-power microwaves (Strategic Defense Initiative) and high-energy-density materials.

The 1990 DOD list differs slightly from that of 1989. Consisting of 20 technologies, it includes two technologies not included in the original list—high-energy-density materials and weapons systems environment—and merges several of the other 1989 technologies. In selecting the 1990 critical technologies, the 1989 criteria were applied, along with two additional criteria: pervasiveness in major weapons systems and strengthening the industrial base. The latter was added to "reflect explicitly the growing concern for spin-off to the industrial base." It seems equally likely that it reflects a concern for "spin-on" to defense from commercial technologies.

The 1990 DOD plan provides estimates of the amounts in the DOD and DOE budgets for the support of the development of each critical technology. In addition, it assigns three levels of priorities to the 20 critical technologies. The system of priorities is not very detailed and places lowest priority on emerging technologies. Little information is provided on how the priorities would affect funding decisions.

DEPARTMENT OF COMMERCE REPORT

The Department of Commerce (DOC) has identified 12 emerging technologies, defined as technologies that offer substantial economic benefits for

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U.S. industry by the year 2000. Technologies were included if they had the potential to (1) "create new products and industries with markets of substantial size," (2) "provide large advances in productivity or in the quality of products produced by existing industries which supply large, important markets," or (3) "drive the next generation of R&D and spin-off applications."

The purpose of the DOC emerging technologies report is to "provide a source of information to be used by industry, labor, government, and academe as programs and policies are developed to exploit new, emerging technologies." It explicitly states that it "is *not* intended to set out a limited set of technologies which the government has pre-selected for support," but rather reflects an assessment of promising fields with large potential economic impact.

The DOC report also identifies 13 policy areas "where actions could be defined and implemented toward improving the climate and capabilities for competitive economic development of all emerging technologies." They are grouped according to degree of government-industry interaction, ranging from government leadership, to government-industry coordination or cooperation, and industry leadership.

COMPUTER SYSTEMS POLICY PROJECT REPORT

Another report, *Success Factors in Critical Technologies*,identifies technologies critical to the computer systems industry. It was published by the Computer Systems Policy Project (CSPP), a group of 11 chief executive officers from the computer systems industry formed to develop and advocate a public policy agenda for that industry.

Based on analyses conducted by the chief technologists from each of the 11 companies that are represented on the CSPP, the report identifies 16 critical technologies upon which America's computer industry will depend into the next century. They are technologies that are essential to the development and production of future generations of competitive computer systems.

In addition, the CSPP critical technologies report identifies critical success factors which, if improved, can enhance U.S. performance in the technologies. In this way the report seeks to provide guidance to government and industry on where to focus to improve policies that can bolster the U.S. computer system industry's competitive position.

AEROSPACE INDUSTRIES ASSOCIATION REPORT

The Aerospace Industries Association (AIA), which represents the major U.S. aerospace companies, published a report in 1987, *Key Technologies for the 1990s*, which identifies and describes eight technologies that have been determined to be most important to the future competitiveness of the U.S.

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aerospace industries. The criteria that were used to select the key technologies and their definitions are:

- multiple use—for both military and civilian applications
- enabling and high leverage—to get more output from R&D input
- long-term, generic, and high-risk—to allow cooperative planning at a precompetitive stage
- needs more emphasis—a judgment that funding levels may be inadequate.

The report also proposes a national strategy of cooperation among industry, government, and academia on focused development of key enabling technologies to regain the U.S. aerospace industry's world leadership.

Since the 1987 report, the number of AIA key technologies has grown to 11. The AIA, through its National Center for Advanced Technology (NCAT), has been preparing technology development plans for each key technology, such as advanced composites and artificial intelligence. For each technology, a lead firm coordinates a Technology Team (composed of industry, government, and academic experts) in reviewing and validating the technical content of industry-developed "road maps" for technology advance. Subsequently, the road maps are refined into more detailed National Technology Development Plans; plans have been produced for rocket propulsion and advanced composites to date.

The overall goal of the planning effort is to get a consolidated and coordinated national plan for each key technology, including resources, facilities, programs, and goals. The plans will then be used as guidance for industry-government-academia cooperation in development of the technologies.

COUNCIL ON COMPETITIVENESS REPORT

The Council on Competitiveness report, *Gaining New Ground*, identifies a core group of 23 technologies that are basic to the performance of nine U.S. industrial sectors.[11] Criteria for identifying technologies as "critical" are not explicit. Lists of critical technologies were generated by senior technology experts from each sector and verified with leading executives from business, labor, and academia. These technologies were then combined into a master list and again verified with a broad group of experts.

The Council's analysis focuses on technologies that will be important over the next 10 years. The 23 technologies are divided into 5 categories: 1) materials and associated processing technologies, 2) engineering and production technologies, 3) electronic components, 4) information technologies, and 5) powertrain and propulsion technologies. As noted in the previous section, the Council's report also makes recommendations for public policy and private-sector management related to technology.

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Areas of Growing Consensus

With the completion of these reports, have we made significant progress toward a national policy for strengthening technology development and use as a source of U.S. advantage in global competition? A review of the reports reveals that consensus is growing around some key ideas. Admittedly, consensus does not mean that an approach is right. Nonetheless, in our political system the broader the consensus that can be achieved, the more likely that significant changes will take place.

One of the most visible changes in the policy discussion in recent years has been the increase in the number and variety of players. Preparation of the reports has involved representatives of government (both the executive and legislative branches), industry, academe, and labor—often working together. Broader participation reflects a widespread concern about U.S. problems in commercial technology and international competitiveness, as well as critical needs and dependencies in military technologies. The involvement of more of the major political players, which represents a distinct change from earlier phases of the technology policy debate,[12] increases the chances of technology policy issues being addressed in a more comprehensive, systematic, and farsighted manner than in the past.

IMPORTANCE OF TECHNOLOGY TO COMPETITIVENESS

The importance of technology to competitiveness is not at issue among the reports reviewed here. The issues addressed concern the public and private roles and policies necessary to manage technology in the global competitive struggle. The groups producing the reports, however, were often established to serve as advocates for technology. There are other groups, for instance macroeconomists and economic policy officials, for whom the importance of technology is very much at issue.

DECLINING U.S. TECHNOLOGY LEADERSHIP

Declining U.S. leadership in technological capability is an underlying theme running across the reports. In many, if not most, of the technologies the reports find a trend toward declining relative U.S. capability compared to the Japanese and Europeans. The Department of Commerce, for example,

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predicts that, if current trends continue, by the year 2000 the United States will lag behind Japan in most of the emerging technologies and will trail the European Community in several of them. The Council on Competitiveness report *Gaining New Ground* goes further and concludes that the United States has already lost several technologies that are critical to industrial performance and is weak or losing badly in others. Moreover, it states that in most of the critical technologies the U.S. position continues to erode.

The CSPP report and the Council on Competitiveness report *Gaining New Ground* attempt to identify the characteristics of technologies in which the United States appears to be maintaining a lead. The reports reach similar conclusions: the United States tends to maintain a lead in technologies that stress creativity, that are closer to basic research, and that are less capital-intensive. The United States tends to lag in technologies that are capital-intensive, that have a significant manufacturing focus, or that have been targeted by foreign governments and industry.

NEED FOR A BROAD-BASED RESPONSE

There is increasing agreement on the need for a broad-based, coordinated response to the challenges of technological innovation and international competitiveness. There is virtual consensus among the reports that private industry bears the primary responsibility for commercial technology development and application. However, industry, government, labor, and academia are all acknowledged to have important roles to play. These groups are looking for new ways to work together. As *Picking Up the Pace* says, success ultimately depends on a team effort.

Progress along these lines is illustrated by the Bush technology policy statement which explicitly accepts a federal responsibility to work with industry in the development of generic, precompetitive technologies. Also, compared to previous cycles of the technology policy debate, the industry reports give less sense that industry is asking government for special favors and more sense that industry is accepting shared responsibility. A much lower level of agreement, however, exists on the specifics of the respective roles and responsibilities of the various parties, as will be discussed in the next section on unresolved issues. Also, as mentioned above, important policy groups remain outside the consensus on the importance of technology to competitiveness.

CRITICAL TECHNOLOGIES

Another highly visible new dimension of the technology policy debate is the identification of critical technologies. The lists of critical technologies can be used in the allocation of public and private investments to new technologies and to show the country where new priorities should be established. They have the potential to provide a focal point for national tech-

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nology plans that can guide government, industry, and academic actions to renew technological leadership and competitiveness.

As can be seen from Table 3, there is considerable overlap among the various lists of critical technologies. High-performance computing, advanced semiconductor devices/microelectronics, high-density data storage, and optoelectronics are listed as critical in five reports. Advanced materials, artificial intelligence, digital-imaging technology, manufacturing technology, sensor technology, and superconductors are listed as critical in four reports. Biotechnology, medical devices, and air-breathing propulsion appear on three lists. These presumably are critical technologies where public and private investments might have payoffs in multiple sectors of the economy.

There is considerable overlap between critical defense technologies and critical commercial technologies. Only five of the defense (DOD) critical technologies are not included in the DOC list or one of the other lists. This tends to support the view that commercial technologies are critical to the U.S. national defense and vice versa. The overlap also underscores the importance of DOD R&D funding for commercial technologies. Of the 10 technologies on the AIA list, 9 also appear among the 22 DOD (1989) critical technologies. Thirteen of the 16 technologies critical to the computer systems industry also appear on the DOD list.

The similarity between lists of critical technologies has been widely noted. The report of the National Critical Technologies Panel, for example, reviews earlier critical technologies reports and notes the extensive overlap among the lists. Lists of critical technologies, which include many of the same technologies, have also been published by groups in Japan and Europe.[13]

There are limits to the significance that should be attached to the lists—the definitions of the technologies are often quite broad and are not consistent across the reports; the lists are based on different criteria, methodologies, and time horizons. Nonetheless, the overlap among critical technologies lists indicates a strong consensus that these are the broad technologies that will underlie global competition in the next decade or so and that countries and industries will have to possess well-developed capabilities in these technologies to compete successfully.

This consensus sets the stage for the next steps. There is now a strong feeling, expressed by the National Critical Technologies Panel, that

> "...identification of critical technologies is not the problem. The challenge is to develop and deploy them, swiftly and strategically."

GENERIC AND DUAL-USE TECHNOLOGIES

Related to the idea of critical technologies is the idea that certain technologies are "precompetitive," "generic," or "dual-use." As mentioned earlier, "precompetitive" refers to a stage of the technology development process that occurs before commercial potential can be assessed. "Generic"

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technology refers to technology that has potential for applications in a broad range of products and processes. "Dual-use" technologies are those technologies with applications in both the military and commercial spheres.

The currency of these ideas reflects an increasing focus on potential applications of R&D and emerging technologies—that is, on the potential payoff to investment in technology development. This is a response to criticisms that the United States has excelled at technology development but has fallen down at getting the new technology to the market.

The use of these terms reflects an attempt to inject more precise distinctions into the traditional classification of R&D used for federal funding purposes—basic research, applied research, and development—and thus to provide a more discerning basis for determining the relative roles of the federal government and the private sector. The concepts of generic, precompetitive, and dual-use technology include a recognition that at early stages of development of a technology it is impossible to tell what types of applications, if any, the technology may have and what the value of those applications might be. The high uncertainty and risk at these stages, and the probability that the originator of the technology will not be able to appropriate an adequate return on investment, raise the possibility of market failure—that is, underinvestment in technology development by the private sector (from a societal point of view)—implying a need for government action.

This argument provides an economic rationale for government involvement in the early stages of a broader range of technologies than has been traditional. However, if a technology has been identified as critical to competitiveness in the next 10 to 15 years, private firms should also have a strong incentive to invest in its development and application. Hence, critical technologies identified as generic, precompetitive, or dual-use would appear to make good candidates for cooperation between the public and private sectors.

PROMINENCE OF DEFENSE-RELATED ISSUES

Defense-related issues have assumed increasing prominence in the U.S. technology policy debate. It is increasingly recognized that industrial competitiveness is a prerequisite for national defense, as well as for a growing standard of living.

The new defense interest in the competitiveness of U.S. civilian industry has largely been spurred by the growing dependence of U.S. military security on many areas of commercial technology. As noted in the Carnegie Commission reports, in many fields technological leadership has shifted from the military to the commercial sector. This has raised concern, reflected in the DOD critical technology plans, that the declining competitiveness of U.S. manufacturers can weaken defense production. A related concern is that procurement and other regulations make it increasingly difficult for DOD to gain access to commercial technology.

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Some proponents support extension of current defense-related activities as an evolutionary approach to a broader national technology policy. *Technology and Economic Performance* and other reports have proposed transforming DARPA into a National Advanced Research Projects Agency to help in creating a national, rather than solely military, technology base. The DOD's *Critical Technologies Plan* is viewed by some as the first step toward a broader national technology policy—one perhaps not limited to defense technology.[14] The Critical Technologies Institute, which would be funded by the DOD, is also viewed by some as offering the possibility of analytical support for technology policy more broadly. DOD currently provides the federal funding for the first industry-led, industry-government civilian technology development consortium—SEMATECH.

Proposals made elsewhere support this view. Some observers, noting the absence of an effective institutional structure for technology policy on the civilian side of the federal government, have called for the DOD to play a role similar to that played by the Ministry of International Trade and Industry (MITI) in Japan. Such a role for DOD might be acceptable if the definition of national security is widened to include economic health. Other observers, however, object to such a role for DOD on a variety of grounds.[15]

NEW UNDERSTANDING OF THE INNOVATION PROCESS

Another new aspect of the policy discussion as reflected in these reports has been the emphasis on the need for a new understanding of the process of technology development and deployment. The new understanding, which may be characterized as a "systems" perspective, recognizes the need for closer integration among the activities in the innovation process—e.g., research, development, manufacturing, and marketing.

It also recognizes the need for better integration between the innovation process and the broader politico-economic system. This leads to calls for a supportive financial environment; for a healthy technology base of human resources, facilities, and research support; as well as for supportive government policies in many areas.

Finally, a more systematic and integrated view of the innovation process leads to increased recognition of the importance of technology diffusion to economic productivity and competitiveness. .This results in a new emphasis on broader diffusion of existing technology to modernize manufacturing.

POLICY RECOMMENDATIONS

Recent technology policy reports agree that changes in a broad range of government policies are desirable to promote technology development and use and, thereby, to contribute to the achievement of national economic and defense objectives. As noted earlier, some of the reports, such as the Coun-

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cil on Competitiveness' report *Gaining New Ground*, include recommendations for changes in industry and academia. However, the main thrust of the technology policy recommendations is for government action.

A categorization of recommendations is shown in Table 2. The reports call for actions aimed not only at technology development and use directly, but also at the conditions that promote or impede technology, including the financial environment, harmonizing U.S. policies (such as antitrust and regulation) with competitiveness objectives, human resources, international trade, governmental S&T policy, leadership and consensus, and the knowledge base.

Table 4 indicates the types of recommendations made in each report. A check does not necessarily indicate agreement among the reports on desirable actions, but merely that the reports make recommendations in that area. Areas where convergence seems to be occurring are summarized below.

Critical Generic Technologies

Strengthening government support of critical generic technologies is recommended by several of the reports. The reports *Gaining New Ground* and *Technology and Economic Performance* make increased federal support of critical generic technologies a centerpiece of their recommendations. The OSTP technology policy statement acknowledges a federal responsibility to support precompetitive research on generic, enabling technologies. The Council on Competitiveness report *Picking Up the Pace* and the NAM report support these initiatives and call for further action along these lines.

Picking Up the Pace, *Technology and Economic Performance*, and the NACS first annual report encourage Department of Defense efforts to strengthen the U.S. industrial technology base. The OTA report suggests the establishment of a Civilian Technology Agency, which would build on NIST's Advanced Technology Program, to cooperate with industry in selecting and supporting R&D on civilian technologies.

Federal Laboratories

Another series of recommendations focuses on the federal laboratories. The Carnegie Commission and the Council on Competitiveness recommend a review of the federal laboratories for the purpose of recommending whether to close, consolidate, or expand individual labs.

The NAM report recommends more industry involvement in setting the research agenda of the federal labs and focusing selected labs on technologies relevant to industry, such as manufacturing processes.

The OSTP technology policy statement makes several recommendations to improve transfer of federal laboratories' R&D results to the private sector and to increase collaboration among the federal laboratories, industry, and universities. Further strengthening technology transfer funding, charters,

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TABLE 4 Types of Public Policy Recommendations Made by Technology Policy Reports

TYPES OF RECOMMENDATIONS	OSTP	OTA (M)	CAR I	CAR II	COC (P)	COC (G)	EPI	NACS	NACS (CIS)	NAM
TECHNOLOGY	✓	✓	✓	✓	✓	✓	✓	✓		✓
GOVT. R&D	✓		✓	✓				✓		✓
GOVT. TECH. ACQUISITION	✓		✓							
GOVT. TECH. DEPLOYMENT	✓		✓							
GOVT. SUPPORT OF GENERIC TECH.	✓	✓		✓	✓	✓		✓		✓
FED. LABS & COMMERCIALIZATION	✓	✓	✓		✓	✓				✓
TECHNOLOGY INFRASTRUCTURE						✓				
INDUSTRIAL EXTENSION		✓					✓			
STANDARDS	✓							✓		
COOPERATION	✓	✓								✓
USING FOREIGN TECHNOLOGY		✓								
FINANCIAL ENVIRONMENT	✓	✓			✓	✓		✓	✓	✓
FISCAL POLICY		✓			✓			✓		✓
CAPITAL COST		✓						✓		
TAX POLICY	✓	✓			✓	✓		✓	✓	
SAVINGS		✓						✓		
LEVERAGED BUY-OUTS		✓						✓		
HARMONIZING U.S. POLICIES	✓	✓			✓	✓		✓		
ANTITRUST	✓	✓						✓		
INTELLECTUAL PROP. REG'N.	✓	✓						✓		
REGULATION	✓				✓					
PRODUCT LIABILITY	✓									
VOICE FOR COMPETITIVENESS		✓								
HUMAN RESOURCES	✓	✓						✓		
WORKER TRAINING	✓	✓						✓		
PRESCHOOL								✓		
PRIMARY/SECONDARY		✓						✓		
HIGHER EDUCATION								✓		
FOREIGN STUDENTS								✓		
USING ENGINEERS BETTER		✓								
MULTI-LEVEL	✓									
INTERNATIONAL TRADE	✓	✓			✓			✓		
UNFAIR TRADE					✓			✓		
EXPORT CONTROLS								✓		
TRADE-RELATED INTELL. PROP.	✓	✓						✓		
S&T POLICY MACHINERY	✓		✓	✓	✓	✓	✓	✓		
WHITE HOUSE			✓	✓	✓	✓				
CONGRESS					✓					
COORDINATION W/ STATES	✓				✓		✓			
COMMERCE								✓		
DEFENSE			✓							
LEADERSHIP				✓		✓				✓
KNOWLEDGE BASE		✓		✓	✓		✓			✓

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and associated policies (i.e., licensing and intellectual property) of government agencies is recommended by the Carnegie Commission and the OTA. Personnel exchanges between industry and government laboratories are recommended by both NAM and COC. More cooperative research between industry and government labs is recommended by NAM.

Industrial Extension and Regional Economic Development

Two reports specifically support the Manufacturing Technology Centers program at the National Institute for Standards and Technology. The OTA and the Economic Policy Institute both suggest more funding for the Manufacturing Technology Centers and for state industrial extension services.

Fiscal Policy

In the area of fiscal policy, the reports by OTA, the Council on Competitiveness, and NAM, as well as the NACS first annual report, call for reduction of the federal budget deficit to promote a sound environment for strengthening U.S. competitiveness.

Tax Policy

There is broad support for making the Research and Experimentation tax credit permanent. Six reports support this measure. Those six are the NACS first annual report, the NACS capital investment report, both reports by the Council on Competitiveness, and the reports by OTA and OSTP. Support for reinstating the investment tax credit or other form of rapid depreciation is found in the two NACS reports and the OTA report. Support for reduction in the capital gains tax is found in the reports by OTA and OSTP, and the NACS report on capital investment.

Antitrust

In the area of antitrust, the OTA and NACS reports support extending provisions of the National Cooperative Research Act to cover joint production to reduce the legal uncertainties of such cooperative activities. The OSTP statement supports eliminating punitive treble-damage awards under certain circumstances.

Human Resources Environment

Human resources issues are receiving considerably more attention today in relation to technology policy than they have in the past. The recent technology policy reports show support for federal action at several levels of education and training. The OSTP statement recommends the revitalization

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of education at all levels, "not only the training of scientists, engineers, and the technical workforce, but also educating our population to be sufficiently literate in science and technology to deal with the social issues arising from rapid scientific and technical change." Individual reports recommend programs aimed at worker training (OTA and NACS annual report), preschool (NACS), primary and secondary education (OTA and NACS), and higher education (NACS).

Trade-Related Intellectual Property

Three reports—OTA, the NACS annual report, and OSTP—support international efforts to harmonize patent laws and application procedures. The OTA suggests that serious consideration should be given to such harmonization even if it requires substantial changes in the U.S. patent system, as it might.

Government S&T Organization and Policymaking Machinery

Government organization and policymaking machinery for science and technology (S&T) are receiving more attention than in previous years, reflecting the development of a new understanding of the importance of the federal role in providing an environment conducive to innovation and competitiveness.

The Council on Competitiveness report *Picking Up the Pace* and the Carnegie Commission reports make recommendations aimed at improving White House S&T policymaking. The Council on Competitiveness recommends appointment of an Assistant to the President for Science and Technology with specified responsibilities. (This was implemented in 1989 with the appointment of Dr. Bromley.) The Carnegie Commission report, *New Thinking and American Defense Technology*, recommends establishment of a combined advisory panel on S&T and national security issues to advise the President. (This was done in 1991 via the establishment of a national security committee of the President's Council of Advisers on Science and Technology [PCAST].)

Technology and Economic Performance recommends that the OSTP exercise lead responsibility in the Executive Office for identifying, formulating, and evaluating policy issues related to the national technology base for consideration by other appropriate Executive Office councils and offices. It also recommends that the National Security Council should include in its purview broad issues of science and technology policy related to strengthening the national technology base.

Three reports address coordination of federal and state technology programs. The Council on Competitiveness in *Picking Up the Pace* and the Economic Policy Institute in *Modernizing Manufacturing* recommend that federal coordination with state technology programs be strengthened. The

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OSTP recommends that federal programs in such areas as education, training, the national infrastructure, and generic technology centers should build upon state initiatives.

Presidential Leadership

Some reports argue that the President of the United States is uniquely situated to exert the leadership necessary to enact and implement a national technology policy. The Council on Competitiveness in *Gaining New Ground* calls for the President to act immediately to make technological leadership a national priority. The Carnegie Commission suggests that a presidential directive be issued to implement the recommendations in its report *Technology and Economic Performance*. The NAM recommends that the President should lead a public information campaign aimed at elucidating the relationship of manufacturing and technology to competitiveness and well-being.

Knowledge Base

The NAM, the Economic Policy Institute, and the Carnegie Commission all address inadequacies in the knowledge base and analytical support for technology policy. The NAM report calls for restoring and strengthening the Commerce Department's data collection and analytical capabilities to improve understanding of international competitiveness. The EPI report recommends federal programs of research and evaluation of industrial extension and manufacturing modernization programs. The Carnegie Commission report *Technology and Economic Performance* recommends increasing the technology policy analysis capability of OSTP through a dedicated in-house staff and through the recently mandated Critical Technologies Institute.

Opposing Views on Specific Recommendations

In a few cases reports address the same policy areas but disagree on what action to take. For example, the OTA suggests an excise tax on gains from stock turnovers if the stock was held for 180 days or fewer, aimed at discouraging rapid, speculative turnovers of stock. The NACS, on the other hand, opposes a "speculation tax" on the grounds that it would depress stock prices and raise the cost of capital generally, and that the effects of such a tax on speculative turnover are unproven. Similarly, the OTA suggests a variety of measures to limit hostile takeovers, while the NACS opposes such limitations.

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Unresolved Issues

Although agreement on key points is clearly growing, major issues in U.S. technology policy discussions remain unresolved.

THE ROLE OF THE FEDERAL GOVERNMENT IN COMMERCIAL TECHNOLOGY

Despite all the recent activity and attention to the issue, the specifics of the appropriate role of the federal government in commercial technology remain unresolved. The importance of government policy in providing an environment conducive to industrial innovation and competitiveness is widely acknowledged. At the level of specific individual federal policies and programs to stimulate commercial technology, however, there is less agreement.

There is broad support for the traditional federal role in supporting basic scientific research and technology development and acquisition for specific federal missions, most notably national defense. There is increasing concern, however, that this is not enough to maintain U.S. technological competitiveness and support seems to be growing for broader government involvement in generic commercial technologies.

Such programs are often associated with "industrial policy," however, and the position of the White House remains uncertain in some observers' minds.[16] Although the concept of generic technology is embraced in the OSTP technology policy statement, there is uncertainty about the extent to which the statement will be reflected in subsequent government policy decisions and programs. Moreover, budget levels requested for new initiatives such as the Advanced Technology Program at NIST ($47 million in FY 1992) do not seem to represent a significant change in priorities for the Administration.

There is support, as noted in the previous section, for a strong federal role in creating and maintaining a financial environment conducive to innovation and manufacturing by lowering the cost of capital and reducing pressures for short-term profits. There is also support for an increased federal role in improving the human resource base for new technology. However, there is lack of agreement and, in some cases, disagreement on specific recommendations in both of these areas.

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Some of the reports argue that the federal government can help remove impediments to the commercial application of technology by "harmonizing" national policies in areas other than direct support of research, technology development, and technology transfer—such as the budget deficit, tax laws, antitrust, and regulation—with the goal of improved competitiveness. But not all parties agree on these actions.

For example, the OTA report *Making Things Better* analyzes arguments for and against changes in antitrust law to encourage cooperation among firms. It points out that it is difficult to predict how much effect a change would have on the level of cooperation because of the many other factors that affect cooperation. It also points out that a "further weakening of antitrust enforcement could send the wrong signal to business, and invite anti-competitive behavior."

Some reports, such as the first NACS annual report, recommend promoting strategically important industries with low-cost capital or government guaranteed purchases. Most of the reports, however, shy away from such direct government measures. They also, for the most part, stop short of supporting trade policies designed to manage competition from dominant foreign producers or broad industrial policy—i.e., coordinated technology, industry, and trade policies to promote key industries.

RESISTANCE TO REORDERING PRIORITIES

Implicit in the concept of critical technologies is the possibility that, once technologies are recognized as critical, development priorities—both public and private—may have to be reordered. In a time of budget stringency, changing priorities implies reallocation of resources. This engenders opposition from supporters of programs that are not on the list because they fear they will lose funding to the technologies that have been identified as critical.

Thus it is not surprising that there is considerable resistance in the reports to the idea of reordering priorities for technology development investments. Some reports, such as the DOD's 1989 *Critical Technology Plan*, question the wisdom of "disproportionate" funding for a particular "critical technology" taken out of context, without matching increases for related technologies. It argues, with reason, that the promise of critical technologies can only be realized when they are integrated into a balanced science and technology program with a full spectrum of mutually supportive technologies. Steadily improving technologies in diverse areas are an essential part of the overall S&T investment strategy and must not be shortchanged when recognizing the more visible role of the "critical technologies."

Similarly, the Department of Commerce report argues that a "targeted industry" strategy, in which a few technologies or industries are singled out for intensive government support, is not desirable for the United States.

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According to this view, the United States—because it has a large, diversified economy, a large science base, and rich technological resources—should pursue development of as many emerging technologies as possible to diversify risk and broaden the future industrial base.

LEADERSHIP

The question of leadership also remains unresolved. Who will lead the broad coalition of government, industry, and academia that must work together to improve U.S. competitiveness? Who will establish the new priorities and set the new directions? Who will set the policy goals? Who will oversee the implementation of the policy and monitor programs? The difficult structural and investment changes that would be part of a more competitiveness-oriented technology policy can only take place with strong leadership.

Some reports argue that only the federal government, and the President in particular, can provide the necessary leadership for certain needs. They argue that the federal government represents the broad national interest and can serve as the catalyst for bringing together disparate groups in a common cause. These reports tend to recommend strengthening of government organization for science and technology policy so that the government can play a leadership role.

Such calls for federal leadership and coordination of national technology policy are often met with distrust. Several reports call instead for industry leadership. They argue that industry is in a better position than government to identify technologies with potential commercial value and technological areas where the competitive threat is greatest. Some examples of industry-led activities are emerging, such as the AIA's National Center for Advanced Technology, but it is unclear how they will ultimately influence public and private policy.

What is clear is that leadership and coordination mechanisms are needed that will allow and encourage institutions in each sector—government, industry, and academia—to address those aspects of the technological leadership and competitiveness challenge in which they have comparative advantage. The key is establishing a common goal and a shared understanding of what needs to be done and of what the relative roles and interactions of various groups should be in achieving that goal.

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Evaluative Comments

It is beyond the scope of this paper to offer a detailed critique of each report. It is appropriate, however, to make some evaluative comments on the reports as a group.

Most of the reports involve little or no serious original research or data collection and little or no guiding theoretical framework. The critical technologies reports generally follow a "methodology" consisting of generating and applying a set of criteria for selecting critical technologies. Important aspects of the methodology are left vague or unstated, however. Definitions of criteria are quite general and little information is provided on how they were applied. How was it determined, for instance, that a particular technology could "cause revolutionary ... improvements over current products or processes"?[17] Such predictions are highly uncertain under the best circumstances; companies that stake their business fortunes on such predictions are often wrong. There is little in these reports to give one confidence that these predictions are better.

The group consensus process through which these predictions were made is at once a source of strength and of weakness. Although it has led to a widespread consensus that a relatively small number of technological fields will underlie future competitive success, this consensus may simply reflect the faddishness of certain technologies. It is possible that important commercial technologies of the future have been overlooked and that some of the critical technologies will not be so critical. This is not to suggest that the critical technologies reports were not done well, but simply to point out inherent shortcomings in this type of exercise.

Furthermore, the critical technologies identified in some of the lists are so broad that they cannot be very helpful in making resource allocation decisions. Attempting to lead in all the critical technologies that have been identified in such broad terms is effectively the same as trying to maintain a dominant U.S. position across-the-board. We really have not narrowed our focus very much.

Similar criticisms may be made of the technology policy reports. Key terms such as technology, technological capability, technology base, and technological leadership are either not defined or defined in only a general way. Although most of the reports link technology to national economic performance, they are not always precise about what aspect of economic

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performance should be of paramount concern—e.g., economic growth, productivity, or competitiveness. The primary focus of these reports is competitiveness, but most of the reports do not define competitiveness in an operational way.

The reports tend not to differentiate the various segments of U.S. industry, nor to recognize the difficulty in generalizing about the interests and needs of the U.S. industrial community. Most of the reports finesse difficult issues, such as what constitutes an American company when determining eligibility for government-sponsored cooperation or technology transfer. Should a foreign-owned firm be automatically disqualified? What if it manufactures or conducts R&D in the United States? As a result, the reports' recommendations in these areas leave thorny unresolved issues.

The reports leave many questions unanswered, especially those necessary for implementation of the recommendations. The Carnegie Commission report T*echnology and Economic Performance* lists some of the questions that need answers:

> "...the Bush Administration believes that it is appropriate for the federal government to support 'pre-competitive, generic technology.' [footnote omitted] What does this statement mean in operational terms? What are the criteria for deciding which technologies to emphasize? Which departments and agencies should undertake technology support? Where is the proper boundary line between government action and private initiative? Should government support be contingent upon the rapid dissemination of results to accelerate adoption? If so, how can incentives for private development investments be maintained?[18]"

Particularly with respect to critical technologies, the reports say little about the levels of new money needed, where it would come from (i.e., the public or private sector), precisely what it would be spent on, expected results, or timetables.

Although there is increased attention to the problems and potential of technology diffusion and manufacturing modernization, the primary emphasis of most reports remains on new technology development. It is increasingly acknowledged that government, industry, and academia all have important roles to play in technology and competitiveness, but there has been inadequate examination of the parts to be played by small and traditional manufacturers, workers, and citizens.

Although there is broad agreement on the areas of government policy that need to be changed, consensus has not been achieved on many specific policy recommendations. In a few cases, reports have addressed the same recommendation but reached conflicting conclusions on its advisability. For the most part, however, the reports have simply made different recommendations, with the result that there are many different recommendations scattered across a broad range of public policy areas.

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It is possible that if a significantly different approach to U.S. technology policy emerges, it will be driven largely by perceived national defense needs. In a sense this is the path of least resistance in the U.S. policymaking system because of the broad support for a strong federal role in the area of national defense. Such an approach, however, would have serious implications. There are already questions about DOD's efficiency and effectiveness,[19] and it is doubtful in a practical sense that Department of Defense priorities and practices would optimize U.S. industrial competitiveness and economic and social welfare.

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Next Steps

The preceding review of recent technology policy and critical technologies reports leads to the conclusion that some progress has been made toward a national technology policy that supports and promotes U.S. industrial competitiveness, but much more remains to be done. Unfortunately, taken as a group the reports do not provide an unambiguous guide to the next steps that should be taken. Their recommendations are scattered across a broad range of policy areas and they leave unresolved key issues with respect to the role of the federal government in commercial technology, priorities for technology development, and leadership.

In this final section, the author presents her own thoughts on some steps that can be taken to build on the reports reviewed here. These steps are suggested with the recognition that improving U.S. technological capabilities and competitiveness presents a complex and difficult challenge, one that requires a multifaceted approach and a continuing commitment.

Clearly, it makes sense to move forward in the areas in which there is widespread agreement. One of the two recommendations in the technology policy reports with broad support is strengthening the federal role in generic technologies. This could take the form of increasing funding for existing activities such as the Advanced Technology Program in NIST, renewing funding for SEMATECH, and giving the departments and agencies with technical missions the responsibility for funding generic technology under their purview.

The other recommendation for which there is broad support is making the Research and Experimentation tax credit permanent. The groups that prepared these reports may now wish to work together to focus their combined resources on securing adoption of these two key recommendations.

It is also important to keep up the momentum on the critical technologies lists. As noted earlier, the definitions of the technologies should be further refined. More important, their implications for resource allocation (both public and private sector) need to be examined. Such an examination should be continuous and take into account changing patterns of global technological leadership. The Critical Technologies Institute or some other institution should be established to provide a focal point for developing and deploying the critical technologies. Given the increasing interdependencies between civilian and military technologies, any such institution should have

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mechanisms for influencing technology development priorities in the private sector as well. The process of reordering priorities will probably have to be consultative; otherwise, the focal institution will be viewed as a threat to the federal mission agencies and the private sector.

Other changes are needed, although there is less agreement on them. Major changes in federal policy are unlikely without the support and commitment of the President. A President who believes in a strong federal role in generic commercial technology and who is willing to use his office to promote it could play a major leadership role with respect to enactment and implementation of many of the recommendations made in these reports. The President could also use his "bully pulpit" to make the case to the nation about the importance of technology to U.S. national welfare.

Institutional and structural issues need to be given more attention. Stronger technology policy institutions are needed, particularly in the Executive Branch, to improve technology policy formulation and its coordination with economic policy. Consideration should be given to the changes recommended by the Carnegie Commission in the roles of OSTP, the National Security Council, and the Council of Economic Advisers.

Institutions or mechanisms are also needed that can facilitate cooperation among and between various sectors of the economy. The Manufacturing Forum provides one model for encouraging more productive relationships among business, government, academia, and labor. The AIA's Aerospace Technology Policy Forum is another.

It may be possible to make existing institutions work more effectively or take on new responsibilities. This evolutionary approach is embodied in recommendations for transforming DARPA into a NARPA and for giving all the federal agencies and departments with technical missions the responsibility for funding and diffusing generic technology. Existing institutions are often hostile to new missions, however, especially in times of budgetary constraint. Therefore, eventually it may be necessary to establish new institutions—such as the Civilian Technology Agency proposed by OTA.

The current dialogue on U.S. competitiveness problems and the importance of commercial technology needs to be expanded in at least two ways. First, there are important groups of policy makers and scholars that remain to be convinced that the relative technological capability of industry is an important factor in international competitiveness. For example, economist Dale Jorgenson recently argued that the driving force in Japanese competitiveness has been the depreciation of the yen and growth in Japanese labor costs.[20] More effort needs to be made to engage these groups in discussion of the relationship of technology to competitiveness and other measures of economic performance.

Second, the dialogue on technology and competitiveness should be extended to include the public at large. Widespread political support for major policy change and new programs is unlikely to emerge if the public does not comprehend the consequences of lagging technological capability

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and competitiveness for their daily lives. The *Help Wanted* Citizen Information Campaign on Skills of the Work Force, sponsored jointly by the Business-Higher Education Forum and the Public Agenda Foundation, provides a model for public education campaigns on issues related to technology and competitiveness. *Help Wanted* is an intense effort to communicate to the public the consequences—in terms of jobs and quality of life—of not having a first-rate educational system. It consists of coordinated public media information campaigns and town meetings.

Action should also be taken to strengthen both analytical support and the underlying knowledge base for technology policymaking. Technology policy topics for which better data and analysis are necessary include the contribution of technology development and diffusion to national economic welfare, relative U.S. capability in particular technologies, how technological capabilities in certain industries are related to competitiveness in those and other industries, the dynamics of national technological leadership and competitiveness, and the effectiveness of proposed policies and programs.

The proposals for strengthening technology policy analysis and research made in these reports should be pursued. These include establishment of the Critical Technologies Institute and strengthening the data collection and analysis programs of the Department of Commerce. Technology policy research and analysis capabilities in the National Science Foundation and other government agencies, as well as academic institutions, should be strengthened to enhance the quality of the theory and data underlying technology policy decisions.

Industry's primary role in a national technology strategy should be to increase private investment in technology and effectively manage private technical resources to make a profit. A broader range of U.S. industry must come to see technology as the fundamental source of competitiveness. It must become committed to developing and applying technology to produce next-generation products, to reaching the market first, and to continually improving the quality and reducing the price of those products. And, if necessary, it must do so *in spite of* government policies that are admittedly less than optimal.

Industry must also work more closely with the federal government than it has in the past. There are numerous obstacles to this happening. Working closely with government is difficult for industry, because government intervention may benefit some firms at the expense of others. Furthermore, U.S. industry consists of very different sectors with different technological needs and interests. Nonetheless, a number of trends mentioned in the reports—e.g., increasing interdependencies between military and commercial technologies, competition from other countries whose governments support strategic industries, limited resources, and the need to reorder priorities—all require better cooperation between industry and government. The critical technologies may provide a useful focal point for broader industry-government cooperation.

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Finally, changes are needed in attitudes and perspectives to emphasize the values of technological innovation, cooperation, and competition. Leaders in industry, academe, and government can begin to change the cultures within their respective institutions. They can also get the message out to other organizations and sectors through a variety of means, including personal communications, speaking engagements, congressional testimony, oped pieces, and white papers.

Having suggested steps that can be taken toward a national technology policy that is more supportive of U.S. international competitiveness, it is necessary to acknowledge some political and budgetary realities that are for the most part avoided in the reports. In the current climate of conservatism and budget stringency, it is very difficult for the federal government to take the initiative on technology programs that would require large resources or involve the federal government more directly than has been traditional in commercial technology. Moreover, it is clearly impossible in times of budget deficits to increase funding for critical technologies without reducing funding for other technologies, or to boost R&D and industrial investment without giving up something else. For this reason, major policy shifts are likely to occur only in response to strong political pressure and with strong leadership at the highest levels of government, both of which appear to be lacking.

It is commonly said in the technology policy community that the needed changes will only come in response to a crisis of some type. It would be unfortunate if this scenario has to be played out to its end, both because of the painful economic dislocations that would entail and because policy made in a crisis environment is likely not to be good policy. To avoid such a scenario, it is necessary now to begin to implement some of the many recommendations that have been made. Perhaps more important, it is necessary to grapple with the key, unresolved issues of the role of the federal government in commercial technology and the need to reorder priorities in public and private funding for commercial technology—issues that are holding back meaningful progress toward a national technology policy that supports U.S. competitiveness.

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