MANAGING FOR CHALLENGING TIMES: A National Research Strategy

Erich Bloch

PROLOGUE: *Can the United States maintain its stature as the leader in science and technology? In this article Erich Bloch, director of the National Science Foundation, asserts that we cannot take an affirmative answer for granted. He describes the growing pressures on the country's system for conducting research, including new budgetary and political constraints, damage from cumulative neglect of the research infrastructure, and the changing nature and conduct of scientific research.*

To cope with these challenges, Bloch calls for an ambitious national research strategy. Elements of this strategy include a 50 percent increase in support for nondefense basic research, and a doubling of the federal government's share; the redirection of funds from less productive research areas to more critical ones; and greater attention to the quality of undergraduate and graduate education in the sciences and engineering. Implementing such a research strategy, he cautions, will require difficult decisions and renewed self-discipline from scientists, the institutions engaged in conducting research, and the federal government.

Before becoming the director of the National Science Foundation in 1984, Erich Bloch was vice president for technical personnel development at IBM Corporation, which he joined as an electrical engineer in 1952. That year he also received his B.S. degree from the University of Buffalo. At IBM, Bloch was the engineering manager of the company's STRETCH supercomputer system in the 1950s and early 1960s and later headed their solid-logic technology program, which developed the microelectronic technology for IBM's System/360 computer. Bloch also served as chairman of the Semiconductor Research Cooperative and as a member of the board of the Semiconductor Industry Association. In 1985 President Reagan awarded Bloch the National Medal of Technology, in part for his work on IBM's System/360 computer.

The quality and diversity of U.S. research in science and technology remains unmatched by any other nation.[1] This success results from a unique combination of factors. Clearly, the magnitude of the federal commitment to basic research since World War II has contributed significantly. But the productivity of U.S. science and engineering owes an equal debt to the research community's adherence to standards of excellence and to institutional arrangements that have encouraged innovation. The close coupling of research and education in the university setting—a uniquely American invention—and the academic ethos of autonomy, integrity, and pluralism have provided a singularly stimulating climate for research.

However, the very success of this system—and the recognition that science and technology are vital to U.S. economic competitiveness and to national security—have thrown into sharp relief not only its accomplishments but also its weaknesses and the need for change. Some worrisome trends have surfaced, and as a result the national research system has become the subject of serious concern and close scrutiny. The House Science and Technology Committee has undertaken a two-year review of science policy, and several federal and professional organizations are examining the health of the research infrastructure.[2] Peer review and our ways of setting priorities among disciplines are being questioned, as is the appropriate balance of funding between basic and applied research and between large facilities and individual investigators.

Pressure for change in our research system comes from three sources: first, from problems relating to research infrastructure; second, from the larger budgetary, economic, and political environment for research; and third, from developments in the nature and conduct of research itself.

Research Infrastructure. The U.S. research system lacks adequate mechanisms and resources to maintain its infrastructure. Cumulative neglect has led to shortages of manpower, equipment, and facilities, in turn leading to policymaking and remedial action under crisis rather than to thoughtful planning for the future.

We are short of advanced degree engineers to staff our universities and government and industry laboratories, and our production of Ph.D, engineers has been declining since 1976.[3] Only now are there signs that this trend is reversing. Moreover, since 1981 foreign nationals have received over half of the U.S. doctoral degrees in engineering, an increase of more than 100 percent since 1959.[4]

The proportion of R&D scientists and engineers in this country his also dropped; while we were once far ahead of other industrialized nations, we now have only a slight lead over Western Europe and Japan. Both Japan and the Soviet Union produce proportionately more engineers than the United States.[5] Over the next decade this gap could widen as the size of the U.S. college-age population drops, unless a larger proportion of college students decides to major in mathematics, engineering, and the sciences.[6]

The shortage of university research equipment is also cause for concern. Meeting current requirements for new equipment would require approximately $4 billion, and some estimates run as high as $10 billion. Spending on academic research equipment and instrumentation, which declined 78 percent in constant dollars from 1966 to 1983, is now about $1 billion a year.[7]

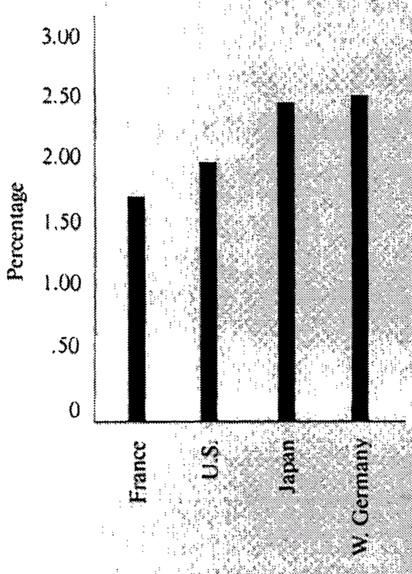
A problem of similar proportions is the deterioration and obsolescence of university buildings and laboratory facilities. A major conference on the topic, held in 1984, concluded that between $15 billion and $20 billion is now needed to build or renovate such facilities.[8]

Moreover, we have an inadequate understanding of the true extent of these problems, as the rough figures cited above indicate, and we lack a monitoring system to warn of impending problems in a timely fashion. This situation derives from the decentralized and fragmented nature of the federal system for research support that developed during and after World War II. We can manage the research system only if we systematically assemble information on requirements for people, equipment, and facilities and then take needed action.

B*udgetary and Political Environment.* We are also confronting major changes in the budgetary and political environment affecting research. For the past five years federal R&D budgets have fared relatively well, but there is little prospect of significant increases in the immediate or medium term. Meanwhile, the total R&D share of gross national product in the United States has fallen in comparison with every other industrialized nation. Twenty years ago we enjoyed a substantial lead; now other nations are drawing even. Moreover, the defense component of U. S. R&D, already larger than in other industrialized democracies, has been the largest beneficiary of recent increases in federal R&D spending. As a result civilian R&D in the United States now constitutes a smaller share of gross national product than in either West Germany or Japan.

Nondefense R&D in 1983

Estimated ratios of nondefense R&D expenditures to gross national product.



Source: National Science Foundation.

While total federal spending for basic research has increased 48 percent in constant dollars since 1972, federal support for basic research at universities has grown only slightly more than the inflation rate. Despite sizable increases in total R&D funds during the current administration, for instance, the National Science Foundation (NSF) budget has remained essentially the same in constant dollars since the mid-1960s.

Meanwhile, demands on the civilian R&D budget for fundamental research have grown. Federal support has nourished university research establishments and has, sometimes deliberately (as in the institutional development programs of the 1960s and 1970s), increased the number of research universities competing for constrained resources.[9] Undergraduate colleges and institutions on the periphery of the research system are also demanding attention. Recently, for example, a group of liberal arts colleges joined in the so-called *Oberlin Report,* which pointed out their vital role in producing science and mathematics majors and urged greater recognition and financial support.[10]

In light of these trends and the deteriorating position of the United States in international trade, the nation's research priorities need reexamination. Defense, energy, and health applications will continue to occupy a prominent place among federal research priorities. We need to balance this emphasis with greater attention to the role of civilian basic research, including fundamental research and the training of scientists and engineers, in supporting these applications and expanding the knowledge base.[11]

The research system's political environment is also changing. As Don

Price, former dean of Harvard University's John F.Kennedy School of Government, has pointed out, the research system is a victim of its own successes.[12] As the public and its representatives realize that scientific discovery leads to practical benefits, political demands on science intensify. Over the past two decades state and local governments have come to see science and technology as a key to economic development. Following the example of California's Silicon Valley, Boston's Route 128, North Carolina's Research Triangle Park, and Austin's recent buildup in electronics, many states have adopted active, technology-based development strategies, and they are leading current efforts to improve the quality of public science and mathematics education.

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Not surprisingly, members of Congress have been showing more interest in appropriations for university research facilities and in the geographic distribution of federal research funds. Their interest has coincided with a new political activism among universities, which, in order to address their shortage of research facilities, are seeking funds directly from Congress, bypassing the traditional process of merit review. In the long run this activism could damage the research enterprise, whose success has been based on self-discipline within the scientific community and on willingness to compete in scientific arenas while remaining aloof from the scramble for political spoils. Political activism will likely persist, however, as will congressional interest in how federal research funds are distributed. This poses some serious questions as to how we can best ensure the quality and effectiveness of the nation's research.

N*ature and Conduct of Research*. Pressure for reassessment and change of our research system also stems from an evolution in the substance and practice of research. The traditional boundaries between scientific disciplines have become blurred, and research that crosses these boundaries has led to some of the most important recent advances. Attention and energy must be focused on these multidisciplinary developments, while protecting the viability of important basic disciplines.

The practice of research has changed in another way. Disciplines long dominated by single investigators in self-sufficient laboratories now require elaborate and expensive instruments that, by financial necessity, must be shared by many investigators. This trend is already familiar in high-energy physics. Its impact on other areas—for example, the reliance of mathematics on computer technology, particularly on supercomputers—is newer but equally significant. These new arrangements are altering the culture and social fabric of these disciplines in profound ways, still not fully understood.

Research is producing new knowledge at an accelerating pace, and the time lag between basic research and applied technology is becoming shorter. In response, cooperation between universities and industries is expanding in such areas as biotechnology, microelectronics, computer hardware and software, and new materials. These new cooperative arrangements benefit both parties but also cause strains within the research system. Private industry's concern over proprietary rights, for example, must be balanced against the importance to academia of unfettered communication.

A related change is that defense and civilian research are no longer as discrete and separable as they once were. Moreover, in dual-use technologies

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that have both military and commercial applications, the private sector, more often than not, provides the stimulus for their development and initial use. One result is that unclassified research at universities now has major military implications. Defining policies that appropriately accommodate national security considerations with concerns for academic freedom and scientific and technical productivity will require open minds and recognition of new realities.

To meet these needs and challenges, the scientific community must devise new strategies to manage our research enterprise and then get on with the job. In doing so, the following agenda must be addressed.

1. Allocate more of our R&D resources to basic research and to the science and engineering infrastructure. The administration has been shifting support from civilian applied R&D to basic research. Between 1980 and 1984 government support for nondefense applied R&D fell, but its support for civilian basic research rose 50 percent.[13] This moved us in the right direction, but not far enough. As the relevance of science and technology increases, the fraction of support devoted to basic research must also increase. Similarly, while industry's support for university research has grown in the last few years, more is needed.[14] Total national funding for basic research amounts to only about $13.3 billion, less than 12 percent of the national total for all R&D.[15] Total funds for basic research should be increased by at least 50 percent, and the federal government should double its share.

The case for this increase is compelling. The opportunities now available in science and engineering research are greater than ever before. Breakthroughs in instrumentation, computation, experimentation, and theory seem to be occurring in every discipline. Multidisciplinary research offers particularly exciting opportunities. Biologists, chemists, and physicists have made major advances in biotechnology, especially in genetic engineering. Materials research brings to bear the insights of physics, chemistry, and engineering to develop substances of high strength, corrosion resistance, or special electrical characteristics. Drawing on the talents of computer scientists, psychologists, and linguists, information science research is revealing a common theoretical ground that enriches all disciplines. The resulting knowledge provides new insights into both human and artificial intelligence

We cannot afford to pass up these opportunities.

2. Reallocate funds from less productive uses to basic research and infrastructure support. Increased funding for basic research need not require an increase in the federal budget. Instead, some federal resources for the support of other R&D areas must be reallocated to basic research. This will require a determined leadership, willing to support new initiatives that will often have to be funded at the expense of programs that are still high is productive but of secondary priority.

Increased support for basic research could come from our national laboratories, which represent an annual federal investment of close to $18 billion. In pursuing the missions of sponsoring government agencies, the national laboratories have expanded scientific and technical frontiers. Recently, however, their vitality and productivity have been cause for concern. A White House Science Council panel, headed by David Packard, chairman of the board of Hewlett-Packard, found that many laboratories have lost a clear sense of their mission and that the quality of their research has declined.[16] The explicit ties between laboratory research programs and their sponsoring agencies have also built in a bias toward applied research and development, which may not result in the most productive use of the national laboratories.

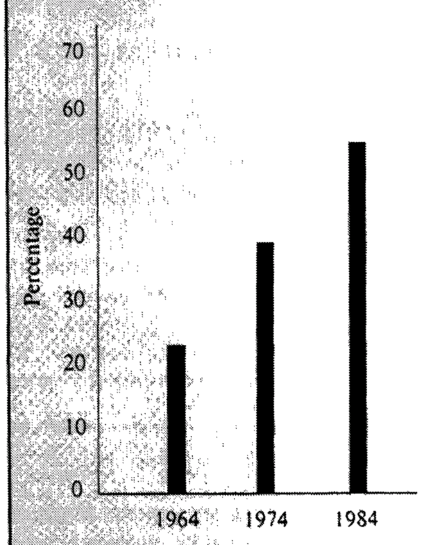
We should recast or expand the missions of some national laboratories to enhance support for basic research and to provide better access for university and industry researchers to the laboratories' major instruments and facilities. In line with past experience, these laboratories should continue to focus on multidisciplinary activities, such as environmental, health, and nuclear research.

3. Rebuild the research infrastructure of trained scientists and engineers, instrumentation, and facilities. Several aspects of our research infrastructure require particular attention: the quality of undergraduate science and engineering education, the limited enrollment in both undergraduate and graduate science and engineering, and the state of university research equipment and facilities.

We need to improve undergraduate science and engineering education throughout the United States. Only a minority of our future scientists and engineers receive their undergraduate training at the major research universities. These universities tend to provide incentives and foster attitudes that value research over teaching. The undergraduate institutions, which place the highest priority on teaching, are hard pressed to buy increasingly expensive research instruments and facilities. Such equipment and facilities are important, however, in attracting faculty to these institutions, in keeping faculty abreast of their teaching fields, and in exposing students to the process of research.

Engineering Ph.D.'s

Growth in Ph.D. degrees awarded to foreign students as a percentage of all Ph.D. degrees in engineering from U.S. universities.



Source: National Science Foundation.

Enrollment in science and engineering will decline along with the size of the college-age population unless we attract a larger proportion of individuals to these disciplines. Women and minorities are a rich source of new talent and are underrepresented in the sciences and engineering. These groups need innovative programs emphasizing early exposure to science and engineering, continuous attention to necessary skills, and encouragement throughout their educational careers.

At the graduate level we must substantially raise the number of U.S. citizens receiving doctoral degrees in the sciences and engineering, reversing a long-term downward trend. We must reduce our overdependence on foreign nationals, whose availability can be seriously affected by foreign policy changes. An adequate supply of advanced degree scientists and engineers is a national imperative and must be so recognized.

The financing of R&D facilities must also be put on a realistic basis. The current shortage and obsolescence of research facilities and equipment arguably results from past shortsightedness. In the 1970s some universities apparently chose to defer building and renovation in order to subsidize tuition costs and so maintain student enrollment and faculty levels.[17] Recent steep increases in tuition reflect the universities' recognition that they cannot continue shortchanging their research infrastructure. The government, too, chose to ignore the true cost of replenishing these assets and now faces difficult short-term funding demands. These demands might have been avoided by a better balance of research support among research, equipment, and facilities, and by realistic depreciation and amortization charges—which still seem the only satisfactory long-term solution.

4. Leverage the effect of federal research resources by stimulating increased support from industry, state and local governments, and other institutions. The magnitude of the tasks outlined here and current constraints on the federal budget mean that responsibility for supporting research and the research infrastructure must be shared by all who stand to gain from them. Increasingly, the federal government will be a catalyst, instead of the sole provider, to facilitate research and lower its financial risk. We can use limited federal funds to help remove obstacles to cooperation between university researchers and industry, and to activate private support for research. We can then set research priorities by taking into account our aggregate national research assets.

Using federal funds as a catalyst may thus not only expand total resources for research but liberate federal funds for deserving projects less able to attract other sponsors. Programs that combine federal funds with matching resources from industry, such as the National Science Foundation's Presidential Young Investigator Awards, Engineering Research Centers, and Supercomputer Centers, have attracted additional funding from both industry and state and local governments.

Similarly, the enhanced federal tax deduction that encourages corporate equipment donations to universities has helped alleviate the shortage of university research instrumentation. Clearly, such techniques will also be an important policy tool for raising private funds to complement federal dollars for the construction and renovation of research facilities.

5. Reform the federal organization for research support. Effective support for science and technology requires improved coherence in federal policies and practices. Most support for science and technology now comes from the mission agencies (for example, the Department of Energy and the National Aeronautics and Space Administration). The National Science Foundation is the only agency charged with overall responsibility for the health of science and engineering.

An alternative proposed from time to time is a Department of Science and Technology. This department might share responsibility with existing mission agencies and complement their primary orientation toward applied research with more systematic attention to basic research and the overall health of the research system. As one recent study suggests, such a department could focus government activities more effectively; encourage interaction among government, industry, and academia; and improve the application of science and technology to national and international needs and issues.[18]

This proposal continues to receive conflicting evaluations both from Washington and from the scientific community. The wisdom of establishing such a department depends on the details of its organization and responsibilities and on whether efficiency and coherence could be gained without undue loss of flexibility and pluralism. The possible advantages of a more coherent federal organization for science must be balanced against these potential drawbacks. Reservations about the details of particular organizational reforms should not stop us from confronting and remedying management problems in the federal research establishment. Like other organizations, government agencies must adjust to new realities and priorities and modify their missions accordingly.

Effective management of the research enterprise requires leadership capable of enunciating coherent policy and preserving a long-term perspective. The president's science adviser and his Office of Science and Technology Policy are responsible for providing such leadership. This leadership can also come from single-agency initiatives and from collaboration among agencies. One recent example is the joint Department of Energy and National Science Foundation plan under which the Argonne National Laboratory would make some of its resources and facilities available to university researchers. Another is the current effort involving the major federal research agencies to increase support for university instrumentation and equipment. More such activities are needed while we continue to consider the broader question of reforming the federal organization for research support.

New roles for institutions, and more cooperative and innovative relationships among them, will require alteration of some deeply ingrained political attitudes.

6. Improve relations and communication among disciplines, institutions, and industries interested in research. How effectively we seize our scientific opportunities and redress deficiencies in the research infrastructure depends, in large part, on how well the nation's research community develops cooperative attitudes and relationships. Within and outside the government, adversarial attitudes that block cooperation must be overcome—but without sacrificing our creative, competitive drive or the distinctiveness of individual institutions. We should continue building relationships among universities, industries, and governments to enhance the flow of people and research results, thereby raising the productivity of the research system.

This premise has prompted the National Science Foundation to devise programs that cross traditional institutional and disciplinary boundaries in such areas as biotechnology, materials science and systems engineering, and computational science and engineering. Arrangements bringing together a variety of actors are not new, although they used to be peripheral to the main research strategy. In the future such strategies will become central.

New technologies will also help break down institutional barriers. Electronic networking, in particular, will allow easy communication across geographic distances and institutional walls. The National Science Foundation is working with the Defense Advanced Research Projects Agency and the university community to plan a nationwide science network.

New roles for diverse institutions, and more cooperative and innovative relationships among them, will require alteration of some deeply ingrained political attitudes. Since these attitudes are frequently reflected in laws and regulations, some of them, too, will need to be changed. For example, until recently antitrust laws were construed as restricting industry collaboration in research. This was clarified by the Joint Research and Development Act of 1984, which promotes joint research ventures. The Mansfield Amendment to the 1970 Defense Authorization Act (which was incorporated the following year into the Military Procurement Authorization Act) also inhibits cooperative research by prohibiting DOD support for nondefense-related research at universities. It needs to be reexamined as well.

As universities and industries collaborate in technology-related research, intellectual property rights must be sorted out. Increased industrial investment in university research and collaboration between industry and university researchers, moreover, may cause some worry that the normally unfettered exchange of information among academic researchers could be curtailed and research priorities distorted. These concerns should not, however, cause us to underestimate the integrity of the universities and their commitment to their traditional role, or industry's appreciation that open academic inquiry is in the best interest of both the university and industry.

7. Enhance the responsiveness of the research enterprise to public con-

cerns while maintaining the integrity and excellence of standards in research. Public demands on science and technology will intensify because of their increasing impact on the nation's economy and security and their influence on the public's work, health, and leisure.[19] The research community must persist in its resolve to sustain standards of scientific excellence in the face of heightened political interest. Failure to do so would squander resources and undermine research productivity. The research community must also exercise self-discipline and adhere to the ethic of excellence and merit competition. To date, its autonomy and freedom from political manipulation have been based on its neutrality and on the promise of an eventual payoff. These will continue to be the most effective bases for a relationship between the scientific community and the public.

The research community must sustain standards of scientific excellence in the face of heightened political interest.

In light of the greater expectations for practical results from our research system, scientists and engineers will have to be increasingly sensitive to the public and political environment. This will require a different type of political involvement than that motivated by the pursuit of research funds. As Daniel Yankelovich observed in an earlier issue of this journal, we hear much about how the public must learn about science, yet "little is said about what science must learn about the public."[20] The point is not so much to improve scientific public relations as to reduce the isolation of scientists from public attitudes and from political debates about science, technology, and their consequences.

The science and engineering enterprise has been called on in the past to address problems of extreme complexity and national importance, such as development of the atomic bomb during World War II and the Apollo program during the 1960s. Circumstances outside the research system drove the extraordinary scientific and engineering accomplishments in these instances. Today there are no such visible, compelling, and unifying issues.

Today's problems, such as economic competition, while strongly dependent on science and engineering for their solution, are more diffuse and less likely to lead to consensus and concerted action. Thus, the research community must construct its own rallying point to sustain the success of U.S. science and engineering. We dare not take our accomplishments for granted.

The agenda proposed here is ambitious but achievable. Our nation does not lack the material, organizational, or intellectual resources to secure the health and productivity of the research system. To bring those resources to bear and to manage them effectively, however, will require tough management, innovative policies, and vigorous leadership. ■

NOTES:

1. The author wishes to acknowledge the assistance of Marta Cehelsky in the preparation of this article.
2. The debate ranges through a number of recent activists and publications. The most notable are: the science policy review by the Science Policy Task Force, established by Rep. Don Fuqua, chairman of the House Science and Technology Committee; the White House Science Council Task Force on Federal/University Relationships; the White House Science Council Panel on Federal Laboratory Review, which published an initial report in 1983 and a follow-up review on the implementation of its recommendations in July 1984; the National Science Board's February 1985 report on Excellence in Science and Engineering Education, which addressed the problem of direct congressional funding of research

facilities; and the November 1984 Conference on Academic Research Facilities sponsored by the National Academy of Sciences, the National Science Board, and the White House Office of Science and Technology Policy. Sections of *Global Competition: A New Reality,* a 1985 report of the President's Commission on Industrial Competitiveness, also bear on research conduct in the United States.

3 National Science Foundation, *Science Indicators 1982* (Washington, D.C.: National Science Board, 1983), 272. Testimony by Simon Ramo before the House Science and Technology Committee's Science Policy Task Force, July 25, 1985, contains a valuable review of manpower shortages in key areas of science and engineering and their implications.

4. National Science Foundation, *Science Indicators 1982,* 228.
5. National Science Board, *Science Indicators 1982,* 6.
6. National Science Board, *Science Indicators 1982,* 78. See also David Davis-Van Atta, Sam C.Carrier, and Frank Frankfort, *Educating America's Scientists: The Role of the Research Colleges*. Report of the Oberlin Conference on the Future of Science at Liberal Arts Colleges, June 9–10, 1985 (Oberlin, Ohio: Oberlin College, May 1985), 7–8. Major reports on the declining quality of U.S. education include Department of Education, Commission on Excellence in Education, *A Nation at Risk: The Imperative for Educational Reform* (Washington, D.C.: U.S. Government Printing Office, 1983); and National Science Board Commission on Precollege Education in Mathematics, Science, and Technology, *Educating Americans for the 21st Century* (Washington, D.C.: National Science Board, 1983).
7. Association of American Universities, National Association of State and Land Grant Colleges, and the Council on Government Relations, *Financing and Managing University Research Equipment* (Washington, D.C: Association of American Universities, 1985), 15. For recent trends, see also National Science Foundation, *National Academic Research Equipment in Selected Science/Engineering Fields, 1982–83* (Washington, D.C.: National Science Foundation, 1985).
8. Conference on Academic Research Facilities, Washington, D.C., Nov. 22–23, 1984, sponsored by the National Academy of Sciences' Government, University, Industry Research Roundtable; the National Science Board; and the White House Office of Science and Technology Policy.
9. NSF and the Department of Health, Education, and Welfare had the latest programs, although the National Aeronautics and Space Administration and the Department of Energy also provided some institutional development support for universities. The NSF programs peaked in 1966 and were eliminated by 1972.
10. *Oberlin Report,* 9–13.
11. See discussion of this point in the recent testimony by Lewis Branscomb, former National Science Board chairman, before the Senate Commerce, Science and Transportation Sub-committee on Science, Technology, and Space, May 2, 1985, especially p. 4.
12. Don K.Price, "Endless Frontier or Bureaucratic Morass?" in Gerald Holton and William A.Blanpied, eds., *Science and the Public: The Changing Relationship,* Boston Studies in the Philosophy of Science, Vol. 33 (Boston: D. Reidel Publishing Co., 1976), 34.
13. National Science Foundation, *Science Indicators 1982,* 40.
14. The United States had the lowest percentage of industry-funded R&D among the industrialized nations in 1970. By 1979 U.S. industry had increased its investment in R&D to 67 percent second only to the French private sector investment in R&D of 71 percent. National Science Foundation, *Science Indicators 1982,* 10.

15. National Science Foundation, *National Patterns of Science and Technology Resources* (Washington, D.C.: National Science Board, in press).
16. White House Science Council, *Report of the White House Science Council Federal Laboratory Review Panel* (Washington, D.C.: Executive Office of the President, Office of Science and Technology Policy, May 1983).
17. Denis P.Doyle and Terry W.Hartle, "It Costs a Small Fortune," *Washington Post,* Sept. 1. 1985, Sec. C.
18. The President's Commission on Industrial Competitiveness, *Global Competition: The New Reality* (Washington, D.C.: U.S. Government Printing Office, 1985).
19. Public opinion surveys conducted over a number of years by NSF and the National Science Board and reported in *Science Indicators* indicate a steady increase in public awareness of science and technology issues.
20. Daniel Yankelovich, "Science and the Public Process," *Issues in Science and Technology,* I (Fall 1984), 11.