Fateful Choices: The Future of the U.S. Academic Research Enterprise

Working Group on the Academic Research Enterprise, National Academy of Sciences, National Academy of Engineering, Institute of Medicine

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Fateful Choices

The Future of the U.S. Academic Research Enterprise

A Discussion Paper

GOVERNMENT-UNIVERSITY-INDUSTRY RESEARCH ROUNDTABLE

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The Government-University-Industry Research Roundtable, established in 1984, is a forum for discussion and debate among representatives of government, universities and industry. Discussions focus on issues related to research that challenge, confound and occasionally divide those in the U.S. research community. The Roundtable does not make recommendations regarding specific government policies or programs. Its purpose is to help all participants develop a better understanding of complex issues, to stimulate imaginative and creative thought and to provide a setting for seeking consensus. The Roundtable is jointly sponsored by the National Academy of Sciences, the National Academy of Engineering and the Institute of Medicine.

The Roundtable's agenda is set by a 25-member Council. The Council's membership is comprised of distinguished scientists, engineers, administrators and policymakers from government, universities and industry. The presidents of the Roundtable's three sponsoring institutions also hold seats on the Council. With the exception of the federal agency officials, who serve as long as they are in office, Council members are appointed to three-year terms.

Through all of its work, the Roundtable Council maintains working relationships with the vast array of parties with an interest in the conduct of research in the United States. These include professional associations, scientific societies, executive agencies, congressional offices, industries and state governments. Contact between the Roundtable and these groups takes place at various venues, including large symposia, workshops and smaller meetings.

Occasionally, working groups are appointed by the Council to examine selected topics in depth. Membership on the working groups is drawn from the Roundtable Council and includes other leading participants in the U.S. research system. The results of working group discussions are reported to the Council, where they receive critical review. Discussion papers, based on the working group deliberations, are disseminated to interested constituencies in the hope of stimulating a wider discussion of these issues.

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With the publication of this discussion paper, the Roundtable working group fulfills its charge to look at both the current status of and future prospects for the academic research enterprise. The Roundtable Council showed great foresight in establishing the group over four years ago. Throughout our work we have benefitted from the guidance and insightful questions by the Council, especially the contributions of Jim Ebert, the Roundtable Chairman, who actively participated in working group deliberations.

John Campbell, the project director, did a superb job of organizing the group's ideas throughout our deliberative process and presenting provocative and constructive ideas of his own. Greg Pearson played a critical role in the writing and editing of this paper. We also wish to acknowledge the guidance and participation of Don Phillips, the Roundtable Executive Director.

Special thanks go to the Andrew W. Mellon Foundation for financial support for the publication and dissemination of this paper. The staff of the National Science Foundation was most helpful in providing statistical analyses of trends in the academic research enterprise.

The document is first and foremost the product of the working group. We hope we have provided a coherent framework for making choices about policies, programs, and resources for the future of the academic research enterprise.

Erich Bloch

Chairman

Roundtable Working Group on the Academic Research Enterprise

PREFACE

One of the major areas of interest for the Research Roundtable has been academic research in the United States. In 1987, the Roundtable Council assembled the Working Group on the Academic Research Enterprise to study this issue. Among the many concerns driving this effort were the changing nature of research, the changing demographics of the college-age population, the increasing financial and human resources required for carrying out research, and the growing expectations placed on academic research. These concerns raised questions about the role of universities and colleges within the U.S. research system, the nation's ability to support academic research, the management of research institutions and the responsibilities of those who sponsor research.

CHARGE TO THE WORKING GROUP

The charge to the working group was four-fold: (1) to examine recent trends affecting academic research in the United States; (2) to consider the impact of these trends on the current academic research enterprise[1]; (3) to identify the longer-term issues that will affect the enterprise in the decades ahead; and (4) to explore ways in which the enterprise might best meet the challenges of the future.

It should be emphasized that the working group was asked to focus its attention on the broad, underlying issues affecting the long-term health of academic research, rather than to dwell on the narrower concerns of the day. In addition, the group was asked to limit its study to the sciences and engineering. Other areas of academic scholarship—the arts and humanities, for example—also merit analysis, but are beyond the scope of the Government-University-Industry Research Roundtable.

WORKING GROUP ACTIVITIES

The working group divided its work into two phases. During the first phase, the working group addressed the status of the current academic research enterprise, reviewed statistical evidence of recent trends, and identified pertinent issues for further consideration. A resulting discussion paper was published in October 1989.[2]

[1] As used by the Working Group, the U.S. academic research *enterprise* refers generally to the group of American universities and colleges performing significant research in the sciences and engineering. The U.S. research *system* refers collectively to all institutions that perform or fund research, including universities and colleges, federally and state-supported laboratories, federal and state research funding agencies, foundations, and industry.

[2] Government-University-Industry Research Roundtable, *Science and Technology in the Academic Enterprise: Status, Trends and Issues*, Washington, D.C., National Academy Press, October 1989.

During the second phase, the working group conducted further analyses of issues identified in the October 1989 discussion paper, paying particular attention to their implications for the future of U.S. academic research. In addition to holding numerous meetings itself, the working group convened five special workshops focused on the phase-two objectives. The workshops, held from March through October 1990, addressed the following topics: the changing organization and management of universities; the future role of universities; the changing conduct of research and its implications for funding agencies; the future of scientific and engineering education; and the future funding of academic research.

For international perspectives on the issues being addressed, the working group benefited from two symposia co-sponsored by the Research Roundtable and the National Science Foundation. The first, in March 1989, focused on the historical evolution of the research systems of six countries: the United States, Japan, the Soviet Union, the United Kingdom, Germany, and France.[3] The topic of the second, in February 1991, was future national research policies, which were presented and discussed by senior government officials and leading scientists directly involved in formulating research and higher-education policies in the United States, Japan, the Soviet Union, the United Kingdom, Germany, and the European Community.[4]

The current program of activities culminated in a national conference on the future of the U.S. academic research enterprise, held December 9-10, 1991, in Washington, D.C. Conference participants were asked to assess the range of options identified by the working group and to explore the possibilities for national consensus on the future of the enterprise.[5]

MAJOR THEMES OF DISCUSSION PAPER

This discussion paper presents the working group's thoughts from its second-phase deliberations and inquiries. The Research Roundtable hopes this discussion paper will stimulate debate within the research community and the public at large about the future course of academic research in the United States.

Part One presents an optimistic and challenging vision of the future of U.S. academic research. In this vision, the working group outlines the significant changes that it believes lie ahead for the research community. These include an emerging global research system, a broadened research work-force, new communication systems, and an expanded role for academic research in advancing social, health, and economic goals.

[3] Government-University-Industry Research Roundtable, *The Academic Research Enterprise Within the Industrialized Nations: Comparative Perspectives*, Washington, D.C.: National Academy Press, March 1990.

[4] Government-University-Industry, Research Roundtable, *Future National Research Policies Within the Industrialized Nations*, Washington, D.C.: National Academy Press, April 1992.

[5] For a summary of the conference proceedings, see Government-University-Industry Research Round-table, *The Future of the U.S. Academic Research Enterprise: Report of a Conference*, Washington, D.C.: National Academy Press, March 1992.

Part Two outlines the steps necessary to pursue this vision. In the view of the working group, two processes need to begin simultaneously.

- First, universities and research sponsors need to take immediate, concrete steps to respond to the changes occurring within the enterprise. The working group believes that decisionmakers at the highest levels need to set overall national research priorities with input from the university and research communities. Universities and funding agencies need to clarify their respective responsibilities for funding university-based research, and they need to update their organizational and management strategies. The research community and universities need to adapt to shifting demographics and the changing value systems of many young investigators. Finally, universities need to improve the quality of science and engineering education, especially at the undergraduate level.
- Second, all those with a stake in academic research—including the political, corporate, and public interest sectors—should begin to think strategically about the future of the research enterprise. To start this process, the working group describes a heuristic framework for considering future options. Central to this framework is a better understanding of the large-scale forces that affect the enterprise: the pace and nature of research, the economy, politics, and international events. Based on a consideration of possible interactions of these forces, the working group sets forth several "scenarios" depicting the future size and structure of the enterprise. The working group then identifies key policies or programs, specific to each scenario, that would be required to maintain the quality and productivity of the enterprise.

Following these two important discussions, the working group outlines several fateful choices that lie at the heart of these near-term decisions and strategic options. These choices will shape the capacity and character of the U.S. research enterprise over the next several decades.

Part Three describes the changing environment for decisionmaking. Wise decisionmaking will require a broad perspective that encompasses the full range of elements essential to the enterprise—people, programs, infrastructure, and financial support. In the view of the working group, innovative approaches to decisionmaking are called for that will require new forms of leadership and a sense of common purpose.

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PART ONE

A Vision for the Future

A VISION FOR THE FUTURE

INTRODUCTION

The academic research community in the United States is heading toward an era of unparalleled discovery, productivity, and excitement. In fields as diverse as computing and materials science, high-energy physics and psychology, cosmology and the neurosciences, university-based research will open new worlds of knowledge and make possible innovations not yet imagined. The research enterprise holds great promise for advancing social, health, and economic goals into the next century.

The academic research community in the United States is heading toward an era of unparalleled discovery, productivity, and excitement. In fields as diverse as computing and materials science, high-energy physics and psychology, cosmology and the neurosciences, university-based research will open new worlds of knowledge and make possible innovations not yet imagined.

This hopeful vision for the U.S. academic research enterprise motivated the working group's deliberations and analyses. To achieve this vision, the enterprise must be guided wisely by current and future generations of investigators, university administrators, the sponsors of research, and the broader public. The working group's strong and positive presentation of this vision assumes that such guidance will prevail.

Dynamic change is a central component of this vision. The research enterprise of the future will be unlike the one of today. Significant opportunities and challenges can be expected in the decades ahead.

A GLOBAL RESEARCH SYSTEM

International research cooperation will become a pervasive feature of the U.S. academic research enterprise in the next century. Multinational research arrangements will be essential for studying such phenomena as large-scale environmental effects and the most demanding experimental problems in the physical and biological sciences. The research communities of both industrialized and developing countries will rely more and more on cooperative ventures to address these and other research problems. Just as foreign-based companies now support research in U.S. universities, in the future more governments and industries are likely to support the research activities of other nations.

Over the next few decades, the number of nations with highly effective research systems will grow. Their university, government, and industry laboratories will collaborate in novel, imaginative, and effective ways. Global competition in science and technology will require that the United States pay close attention to the research activities of other countries, especially those targeting economic growth as their primary research goal. This will be particularly true for the Western European and Pacific Rim countries, which have become fierce competitors in the knowledge-intensive global marketplace. Several of the newly democratized nations of Eastern

International research cooperation will become a pervasive feature of the U.S. academic research enterprise in the next century.

Europe and the former Soviet Union will most likely join in that competition. During the next century, nations in Asia, South America, and Africa can be expected to develop advanced research capacities or actively participate in multinational research programs.

Global competition in research will produce a flood of new and potentially useful information. Just as Japan in past decades capitalized on discoveries made in this country, during the next century, U.S. universities and industries will benefit from the growing base of knowledge and technology produced elsewhere.

Investments in academic research will be a vital ingredient to this country's ability to contribute to the urgent multinational research agenda and to our own continued success in the international marketplace.

International cooperation will take many forms. International research consortia will be created, where funds and personnel are exchanged or shared across national borders in order to address a specific research topic. Governments and industries will make financial contributions directly to and develop contacts with research institutions in other nations. Under such arrangements, research institutions would share research data, provide educational opportunities to young scientists from foreign nations, and in some cases provide licensing rights for patented products resulting from the sponsored research. In the future, it is likely that increasing numbers of U.S. academic scientists and engineers will benefit by travelling abroad to keep up with advances outside the United States.

International scientific cooperation and competition will be viewed by some as a threat to this nation's preeminent position in the world scientific community. On balance, however, these forces will turn out to be positive ones, creating incentives for achievement and excellence. Investments in academic research will be a vital ingredient to this country's ability to contribute to the urgent multinational research agenda and to our own continued success in the international marketplace.

A DIVERSE RESEARCH WORKFORCE

Women and minorities will increase their participation in the academic research enterprise as educators, researchers, academic officers and policymakers.

Women and minorities will increase their participation in the academic research enterprise as educators, researchers, academic officers and policymakers. Women already have substantially increased their participation in several fields, such as biology and chemistry. Minorities, however, are now largely under-represented in all research fields. In the working group's vision for the future, the availability of these pools of potential talent, perhaps more than any other factor, offers the hope that future work-force needs across the whole of the sciences and engineering can be addressed.

Attracting a broader array of young people to scientific and engineering careers—women and minorities as well as white males—will not only promote equity, but also will serve as a vital safeguard in the event of dwindling immigration of foreign research talent. In the past, the United States has relied on foreign scientists and engineers to sustain much of the growth in its research workforce. This may no longer be a dependable source of talent. Other countries, including many developing nations, are develop

ing research systems that will compete directly with the United States for this pool of talent.

NEW COMMUNICATION NETWORKS

This move to worldwide networks will usher in a new era in research. Desktop computers will give scientists around the world access to the latest generation of supercomputers. Investigators will be able to use advanced research equipment located anywhere in the world.

Advances in computers and telecommunications have the potential to fundamentally change many aspects of research and education. In the next century, most researchers will use personal computers as "information ports" to receive and send electronic and voice mail, complex documents, and real-time video images. In many research fields, telecommunications technology will bridge the distances separating individual investigators and research institutions.

This move to worldwide networks will usher in a new era in research. Desktop computers will give scientists around the world access to the latest generation of supercomputers. Investigators will be able to use advanced research equipment located anywhere in the world. One-of-a-kind high-technology research instruments and facilities, such as orbiting telescopes, sophisticated weather satellites, and high-energy particle accelerators, will be accessible from remote sites, as will specialized databases and digital libraries.

New communication technologies also will change approaches to teaching and learning at research institutions. Computer access to large library databases and other sources of information will expand the pool of knowledge available to students. Sophisticated two-way video and data links will make possible long-distance communication between students and faculty located at different sites. These new technologies will supplement, not replace, students' classroom experiences and personal communication between faculty and students.

AN EXPANDED ROLE FOR ACADEMIC RESEARCH

With growing urgency, society will call upon the academic research community to help solve a wide variety of problems related to human health, the economy, the environment, and many social issues.

In the 21st century, the academic research enterprise will be even more important to the vitality of the United States than it is today. Scientific and scholarly judgment increasingly will be relied on to help address complex issues in law, medicine, politics, and government. With growing urgency, society will call upon the academic research community to help solve a wide variety of problems related to human health, the economy, the environment, and many social issues.

The generation and manipulation of information will be of growing economic importance as products and processes progressively become knowledge-based. As in the past, the academic research community will continue to produce new basic knowledge and train new generations of scientists and engineers. An urgent challenge for the future, however, will be to transfer the knowledge gained from basic research more rapidly to the nation's commercial sector. The technologies developed through this transfer process, in addition to improving the nation's economic strength, will be incorporated into new research technologies and instrumentation that will help propel basic research productivity to ever-higher levels.

To fulfill these expanded roles, universities and colleges will need to maintain their dual missions of education and research and their culture of open information exchange. These qualities will ensure that U.S. academic research institutions continue to be centers of innovation.

PART TWO

Achieving the Vision

INTRODUCTION

Two processes need to begin simultaneously. First, universities and research sponsors need to take immediate, concrete steps to "put their houses in order." Second, all those with a stake in academic research—including the political, corporate, and public interest sectors—should begin to think strategically about options for the future of the research enterprise.

Achieving such an optimistic and challenging vision for the future will require choosing among a range of options, each of which will have profound implications for the research enterprise in the United States. All those with a stake in the research enterprise—investigators, university administrators, funding agencies and the larger public—need to understand the implications of these difficult choices. Whatever decisions are made will determine the capacity and character of the U.S. research enterprise of the next century.

In the view of the working group, two processes need to begin simultaneously. First, universities and research sponsors need to take immediate, concrete steps to "put their houses in order." The working group believes that decisionmakers at the highest levels need to set overall national research priorities with input from the university and research communities. Universities and funding agencies need to clarify their respective responsibilities for funding university-based research and their need to update their organizational and management strategies. Universities, funding agencies, and professional societies need to adapt to shifting demographics and the changing value systems of many young investigators. Universities need to improve the quality of science and engineering education, especially at the undergraduate level.

Second, all those with a stake in academic research—including the political, corporate, and public interest sectors—should begin to think strategically about options for the future of the research enterprise. To start this process, the working group describes a heuristic framework for considering future options. Central to this framework is a better understanding of the large-scale forces that affect the enterprise: the pace and nature of research, the economy, politics and international events. Based on a consideration of possible interactions of these factors, the working group sets forth several "scenarios" depicting the future size and structure of the enterprise. The working group then identifies key policies or programs, specific to each scenario, that would be required to maintain the quality and productivity of the enterprise. The working group believes that this heuristic framework brings new ideas to the attention of the research community. This is in keeping with the working group's charge to concentrate on issues affecting the enterprise over the long term.

NEAR-TERM DECISIONS

In an earlier discussion paper,[1] the working group identified several trends that it believes to be symptomatic of underlying long-term changes within the enterprise. While the enterprise is not now in a crisis, the working group believes that these changes require urgent attention by all participants in the enterprise—investigators, university administrators, research sponsors.

The near-term decisions outlined below will not come easily. Without them, however, harmful tensions in the enterprise will persist and, equally important, the public support needed to achieve the optimistic vision set out in this paper will not be forthcoming.

SETTING PRIORITIES

It will be necessary in the coming decades to set national priorities for the support and conduct of science and engineering research. If priorities are not established, there will be increasing confusion about and less than optimal investments in frontier research and in research infrastructure of vital importance to the nation.

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Growth In The Number Of High-Quality Research Opportunities Is Outpacing Increases In Research Funding. The 1950s and 1960s saw an enormous expansion of both the number of university research personnel and the financial resources for the support of university-based research. Following a general steady-state in funding and personnel during the 1970s, expansion and diversification of university-based research resumed during the past decade. All evidence points to a continuation of the trends of the last 10 years: increased numbers of institutions and people involved in research; greater participation of industry, states, and universities in the support of science and engineering; and enhanced university research capacity designed to boost local, regional, and national economic development.

The growth of the past decade has brought many benefits. The enlarged base of support for research has resulted in major scientific and technological accomplishments, and it has enhanced the nation's research and educational capacity. Serious questions are being raised, however, about the nation's continued willingness to support a growing research enterprise. The enterprise itself is experiencing a number of detrimental tensions that threaten its quality, integrity, and ability to respond to new opportunities and challenges.

At the federal level, demand for financial support for research activities is outpacing the recent increases in research funding by the federal agencies. As a consequence, although the absolute number of federally supported

researchers is higher now than at any point in history, competition for research funding is increasing—for both established and younger investigators. This situation is exacerbated by the rapidly increasing costs of doing research—paying the salaries of scientists and engineers, building and maintaining new research facilities, and purchasing new research instruments— and by the simultaneous emergence of several large-scale research projects within federal agency budgets. As a result, tension is growing among investigators, their parent institutions and the agencies that fund them. The high level of frustration expressed by many scientists is but one highly visible sign of the stress these tensions are creating.[2]

The trends of the last 10 years have also put the federally supported peer-review system, used to allocate funds among competing research proposals, under growing strain. Many investigators are having to spend increasing amounts of time as reviewers, leaving less time for their own research. There is also growing concern that greater numbers of conventional proposals are being submitted because investigators fear that innovative, but unorthodox, research projects will not be funded.

Another source of tension is the balance between funding greater numbers of science projects and rebuilding the research infrastructure. Many research facilities are in need of repair, renovation, or replacement. Many laboratories lack state-of-the-art scientific equipment. Fiscal belt-tightening, if continued at the state and federal levels, will undoubtedly compound this problem.

Government Leaders Must Set Broad National Priorities For Research In Consultation With The Individual Scientific And Engineering Disciplines, The Larger Scientific Community, Academic Institutions, And Industry.[3] Such a broad-based process for setting priorities needs to address not only the relative importance of various research projects and programs, but also the funding needs for facilities, instrumentation, education, and training.

Priority-setting at the level of the individual research proposal has worked quite successfully. The research community relies primarily on two criteria to allocate funding: *research excellence* and *impact on the knowledge base*, or the potential of a research proposal to expand the horizons of human understanding. The working group strongly believes these two criteria must continue to be the primary basis for making funding decisions in research. *Originality*, or unique, non-traditional approaches to addressing research questions, will also have to be explicitly considered. This approach will be necessary to address concerns that more "conventional" research proposals are being submitted as a response to increased competition for funding.

Other funding criteria will also play a role in funding decisions. These are: *relevance*, or having eventual application to human needs; *economic promise*, or the potential for accelerating growth in the gross national product (GNP); and *equity*, or the degree to which funding agencies should consider the

geographic location, race, and sex of grant applicants. The challenge for research institutions and agencies that fund research will be to decide on the appropriate mix of these criteria, and to make them explicit. Different criteria will be called for, depending on the goals of those supporting the research.

Processes for setting national priorities across research fields or within the enterprise as a whole work less effectively. Within the federal government, there is no coherent, over-arching strategy for research. This lack of coordination at the highest levels of decisionmaking is a serious problem.

Within research fields, with a few notable exceptions, individual scientific and engineering disciplines are only now attempting to agree on research priorities and to set forth a strategic vision. To be of use to decision-makers who allocate federal research dollars, such priority-setting will need to be adopted more broadly and updated on a regular basis.

Processes for setting national priorities across research fields or within the enterprise as a whole work less effectively. Within the federal government, there is no coherent, over-arching strategy for research. This lack of coordination at the highest levels of decisionmaking is a serious problem.[4,5] Although research priority-setting occurs de facto during the federal budget process, with input from the White House, the Office of Management and Budget, the Office of Science and Technology Policy, Congress, and the federal agencies that fund research, priority-setting across agencies occurs only rarely.

This lack of coordination goes beyond the federal level. The nation's research community has conducted little debate about priorities, and there has been resistance to priority-setting efforts. State government and federal agency officials have only recently begun an informal dialogue about those issues. Few academic institutions have engaged in any kind of long-term strategic planning necessary to set priorities for conducting and supporting research.

Because priority-setting entails important trade-offs, the long-term implications of such decisions must be taken into consideration. The need for investing in the research infrastructure, for example, will have to be weighed against funding a larger number of individual research grants. The importance of investing in large, expensive "mega-projects" will need to be balanced against the desirability of funding a number of smaller research projects.

CLARIFYING FUNDING RESPONSIBILITIES

Ensuring that the essential needs of the enterprise are met within this changing environment requires more explicit focus on the division of federal, state, and university responsibilities in funding academic research.

The financial resource base for academic research is becoming increasingly complex. Through their support for research infrastructure and the indirect costs of research, non-federal sectors now play a much more significant role in setting the research agenda in the United States than they have in the past three decades. Ensuring that the essential needs of the enterprise are met within this changing environment requires more explicit focus on the division of federal, state, and university responsibilities in funding academic research.

Over The Past Two Decades, While Federal Investments In Academic Research Have Increased, Non-Federal Funding Has Grown Even Faster. As a consequence, the percentage of total non-federal academic research funds rose from 31 percent in 1970 to 41 percent in 1990, its highest point since the 1950s.[6] (See Figure 1, page 14.) The rise of non-federal investments in research is most pronounced in public universities. The non-federal share of research funds for public universities rose to 48 percent in 1990, compared with a 29 percent federal share for private universities. (See Figure 2, page 15, and Figure 3, page 16.)

During the same 20-year period, the estimated share of university-generated funds devoted to research grew from 11 percent to 19 percent. The most significant trend in university funding during this time was the willingness of public universities—especially institutions aspiring to develop a stronger research base—to utilize their own resources to cover part of the indirect costs of externally sponsored research.

Although the overall share of academic research funds contributed by state governments held steady at 8 percent, several states greatly increased their spending for academic research. Industry also took a larger role, more than doubling its share of investment in academic research, from 2.8 percent of the total in 1970 to an estimated 7 percent in 1990.

Non-federal sectors now pay about 41 percent of the total for academic research equipment. (See Figure 4, page 17.) For academic science and engineering facilities, the non-federal share of direct funding has risen to 90 percent. (See Figure 5, page 18.)

Policymakers Need To Rethink The Current Division Of Federal-State And Federal-University Responsibilities For Higher Education In General And Research In Particular. This will require more effective ongoing communication, interaction, and coordination among research sponsors and academic institutions.[7]

All sponsors of academic research are currently facing financial constraints. Federal appropriations are constrained by large budget deficits and public resistance to raising taxes. State governments—many of which are confronting their own budget problems—are closely evaluating their priorities, including the support of academic research. Foreign governments and foreign-based industries are potentially important sources of funding for U.S. academic research; however, as global economic competition intensifies, foreign investments could be constrained by government policies.

During the next decade, the ability of most universities to increase their own resources in support of research will be limited. It is unlikely that more funds could come from undergraduate student tuition or state monies appropriated for the educational mission. This is because most universities are facing steady student enrollments and flat or reduced state appropriations, and at both private and public universities, public pressure has slowed the pace of tuition increases. More universities are competing with each other

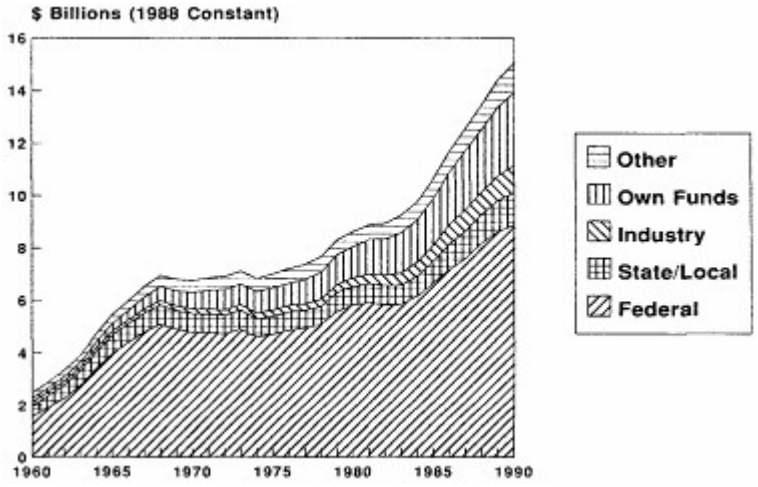

FIGURE 1

Academic R&D Expenditures by Source

Note: Data series within the figures are not overlapped; top line represents total. Financial data are expressed in 1988 constant dollars to reflect real long-term growth trends

Definition of Terms: Academic R&D expenditures include current-fund expenditures within higher education institutions for all research and development activities that are separately budgeted and accounted for. This includes both sponsored research activities (sponsored by federal and non-federal agencies and organizations) and university research separately budgeted under an Internal application of institutional funds; but excludes training. public service, demonstration projects, departmental research not separately budgeted, and FFRDCs. Federal funds include grants and contracts for academic R&D (including direct and reimbursed indirect costs) by agencies of the federal government. State/ Local funds include funds for academic R&D from state, county, municipal, or other local governments and their agencies, including funds for R&D at agricultural and other experiment stations. Industry funds includes all grants and contracts for academic R&D from profit-making organizations, whether engaged in production, distribution, research, service, or other activities Own Funds include institutional funds for separately budgeted research and development, cost-sharing, and under-recovery of indirect costs; they are derived from (1) general purpose state or local government appropriations. (2) general purpose grants from industry, foundations, and other outside sources, (3) tuition and fees, and (4) endowment income. Other sources include grants for academic R&D from non-profit foundations and voluntary health agencies, as well as individual gifts that are restricted by the donor to research.

Source: National Science Foundation, Division of Policy Research and Analysis. Database: CASPAR. Some of the data within this database are estimates, incorporated where there are discontinuities within data series or gaps m data collection. Primary data source: National Science Foundation, Division of Science Resources Studies, Survey of Scientific and Engineering Expenditures at Universities and Colleges.

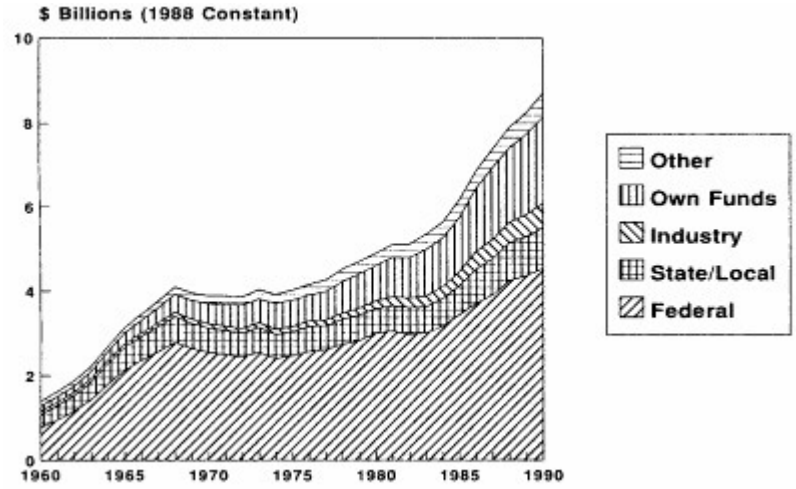

FIGURE 2
Public Doctoral Institution R &D Expenditures by Source of Funds
Note: Data series within the figures are not overlapped; top line represents total. Financial data are expressed m 1988 constant dollars to reflect real long-term growth trends.
Definition of Terms: Public doctoral institutions are institutions that have granted an average of 10 or more Ph.D. degrees per year m the natural sciences or engineering over the past two decades, and are under the control of—or affiliated with—federal, state, local, state and local, or state-related agencies; they include 116 institutions. R&D Expenditures include current-fund expenditures within doctoral institutions for all research and development activities that are separately budgeted and accounted for; excluding departmental research not separately budgeted and FFRDCs. Federal funds include grants and contracts for R&D (including direct and reimbursed indirect costs) by agencies of the federal government, excluding funds for FFRDCs. State/Local funds include funds for R&D from state, county, municipal, or other local governments and their agencies, including funds for R&D at agricultural and other experiment stations. Industry funds include all grants and contracts for R&D from profit-making organizations, whether engaged m production, distribution, research, service, or other activities. Own Funds include institutional funds for separately budgeted research and development, cost-sharing, and under-recovery of indirect costs. They are derived from (1) general purpose state or local government appropriations, (2) general purpose grants from industry, foundations, or other outside sources, (3) tuition and fees, and (4) endowment income Other sources include grants for R&D from non-profit foundations and voluntary health agencies, as well as individual gifts that are restricted by the donor to research.
Source. National Science Foundation, Division of Policy Research and Analysis. Database: CASPAR. Some of the data within this database are estimates, incorporated where there are discontinuities within data series or gaps in data collection. Primary data source: National Science Foundation, Division of Science Resources Studies, Survey of Scientific and Engineering Expenditures at Universities and Colleges.

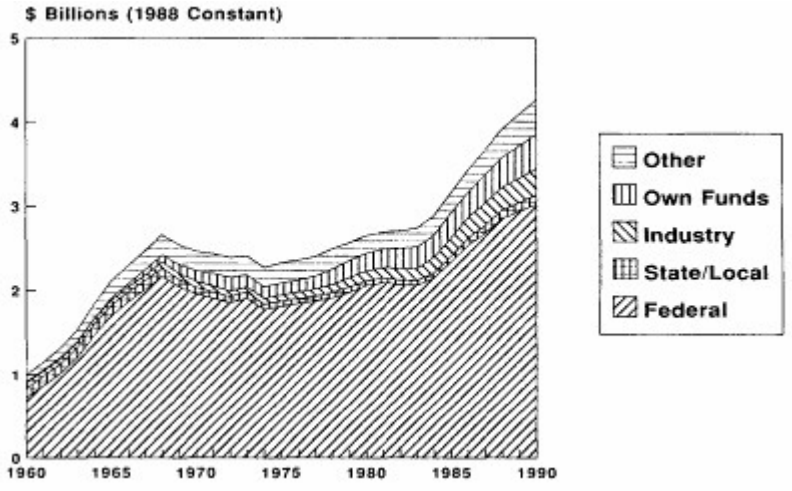

FIGURE 3
Private Doctoral Institution R & D Expenditures by, Source of Funds
Note: Data series within the figures are not overlapped; top line represents total. Financial data are expressed in 1988 constant dollars to reflect real long-term growth trends.
Definition of Terms: Private doctoral institutions are institutions that have granted an average of 10 or more Ph D degrees per year in the natural sciences or engineering over the past two decades, and are under the control of—or affiliated with—non-profit, independent organizations with or without religious affiliation; they include 69 institutions. R&D expenditures include current-fund expenditures within doctoral institutions for all research and development activities that are separately budgeted and accounted for; excluding departmental research not separately budgeted and FFRDCs. Federal funds include grants and contracts for R&D (including direct and reimbursed indirect costs) by agencies of the federal government, excluding funds for FFRDCs. State/Local funds include funds for R&D from state, county, municipal, or other local governments and their agencies, including funds for R&D at agricultural and other experiment stations Industry funds include all grants and contracts for R&D from profit-making organizations, whether engaged in production, distribution, research, service, or other activities. Own Funds include institutional funds for separately budgeted research and development, cost-sharing, and under-recovery of indirect costs. They are derived from (1) general purpose state or local government appropriations, (2) general purpose grants from industry, foundations, or other outside sources, (3) tuition and fees, and (4) endowment income. Other sources include grants for R&D from non-profit foundations and voluntary health agencies, as well as individual gifts that are restricted by the donor to research.
Source: National Science Foundation, Division of Policy Research and Analysis. Database: CASPAR. Some of the data within this database are estimates, incorporated where there are discontinuities within data series or gaps in data collection Primary data source National Science Foundation, Division of Science Resources Studies, Survey of Scientific and Engineering Expenditures at Universities and Colleges.

and with other local and national organizations for the same sources of private philanthropy. In response to these funding pressures, "leveraging" arrangements and "cost-sharing" requirements have become common components of the research-support system. To the extent that leveraging increases the overall level of funds for research, it is beneficial for the entire academic research enterprise. If academic institutions are pressured to cost-share—both for direct project costs and through contributions to indirect costs—and by doing so must reallocate resources from instructional programs to research, the research enterprise is imperiled in the long-run.

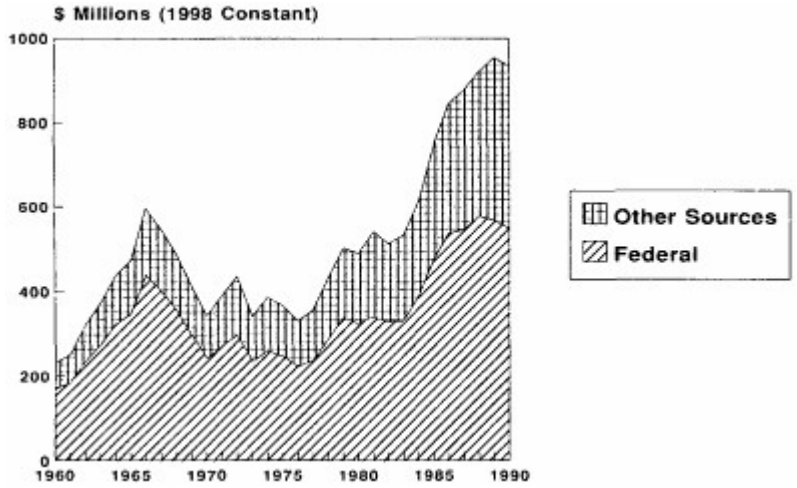

FIGURE 4
Expenditures for Academic Research Equipment by Source of Funds
Note: Data series within the figures are not overlapped, top line represents total. Financial data are expressed m 1988 constant dollars to reflect real long-term growth trends Definition of Terms: Research equipment expenditures include (1) reported expenditures of separately budgeted current-funds for the purchase of research equipment, and (2) estimated capital expenditures for fixed or built-in research equipment and furniture. Federal funds include expenditures for academic research equipment with monies from grants and contracts for academic R&D (including direct and reimbursed redirect costs) by agencies of the federal government; excludes expenditures for FFRDC facilities Other sources include state and local governments, the institution themselves, industry, and other non-profit organizations.
Source. National Science Foundation, Division of Policy Research and Analysis Database CASPAR. Some of the data within this database are estimates, incorporated where there are discontinuities within data series or gaps in data collection. Primary data source: National Science Foundation, Division of Science Resources Studies, Survey of Scientific and Engineering Expenditures at Universities and Colleges

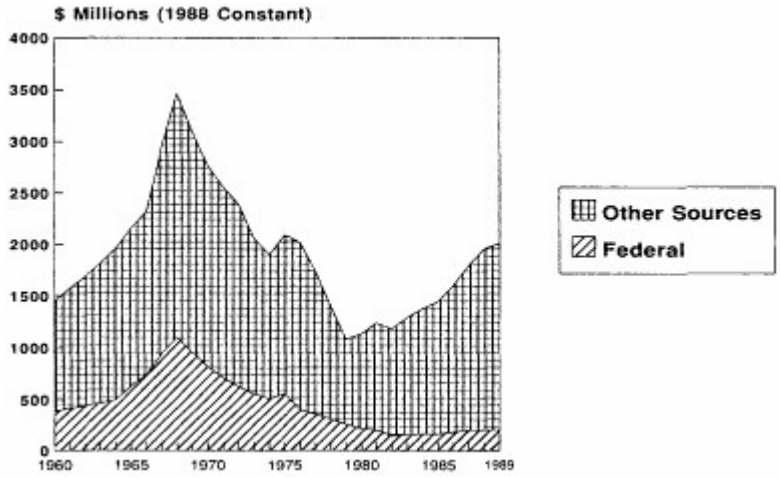

FIGURE 5
Expenditures for Academic Science and Engineering Facilities by Source of Funds
Note: Data series within the figures are not overlapped; top line represents total. Financial data are expressed in 1988 constant dollars to reflect real long-term growth trends. Definition of Terms Academic science and engineering facilities expenditures include capital expenditures for research and instructional facilities, including fixed or built-in equipment, some movable equipment and movable furnishings such as desks, and facilities constructed to house scientific apparatus. Federal funds include expenditures for academic science and engineering facilities with moneys from federal agency contracts in grants. Other sources include state and local governments, the institutions themselves, industry, and other non-profit organizations.
Source: National Science Foundation, Division of Policy Research and Analysis. Database: CASPAR. Some of the data within this database are estimates. incorporated where there are discontinuities within data series or gaps m data collection. Primary data source: National Science Foundation, Division of Science Resources Studies, Survey of Scientific and Engineering Expenditures at Universities and Colleges.

Aspiring research universities may be much more able to put together funding packages for cost-sharing, targeted to selected research programs, than more well-established institutions whose resources already are strained by significant, ongoing commitments to a wider range of research fields. Over the long term, cost-sharing requirements could have profound implications for the allocation of national resources among academic research institutions. The potential effects of cost-sharing requirements on the structure of the research enterprise should be explicitly addressed by research institutions and the government agencies and private organizations that support them.

States traditionally have assumed responsibility for funding a major share of the instructional mission of public universities and colleges. In a few re

search areas, such as agriculture, they also have provided much of the support for research infrastructure and research projects. The federal government, following World War II, assumed major responsibility for supporting research projects and equipment.

In recent years, there has been increasing overlap in the research funding roles of the federal government and the individual states. State governments increasingly are supporting research projects and programs. Some senior federal officials have suggested that the federal government should be involved more directly in the support of higher education in general. At the very least, the states must be full partners in any national dialogue intended to clarify future funding responsibilities for academic research.

IMPROVING ORGANIZATION AND MANAGEMENT

The growing complexity and size of the academic research enterprise require new and innovative organizational strategies. They will be necessary if academic research institutions are to balance their commitments to teaching, research, and public service.

The growing complexity and size of the academic research enterprise require new and innovative organizational strategies. They will be necessary if academic research institutions are to balance their commitments to teaching, research, and public service.

The organization and management of universities have become increasingly complex. The changing nature of many areas of research requires that the departmental structure of universities adapt. For example, multi-disciplinary research teams have become more common as more complex topics emerge in science and technology. Larger-size research teams are increasingly evident, as well. The impact of advances in computers and telecommunications on the conduct and organization for research is yet to be fully felt, but it is sure to require new ways of organizing and managing university-based research.

The average age of university faculty is rising because of the rapid surge in student enrollments and faculty hiring 20 years ago, which was followed by a general steady-state in enrollments and a decline in hiring of younger faculty. Conclusive data are lacking to predict the effects of increased faculty retirements over the next decade. It appears, however, that the pace of faculty retirements may very well accelerate. If retirements do increase, the demand for research faculty could outstrip the supply of available research personnel. This could cause a shift of some presently employed, non-tenure track personnel into faculty positions, or it may result in increased recruitment of investigators from industrial laboratories or from foreign universities.

Universities and funding agencies need to consider new approaches to the organization and management of individual research institutions, and also of the larger U.S. research system. During several workshops held by the working group, the following approaches were raised and discussed.

Good Stewardship. The public is increasing its scrutiny of the process of scientific inquiry and of the stewardship of the taxpayer's mon

ey by academic institutions.[8] While this public attention is valuable, it is a further source of tension within the system. Better management of university resources will serve the interests of both universities and the public. This should include a systematic process for self-evaluation, constant feedback, and an emphasis on improving quality. Better and more visible university-based oversight practices, particularly those designed to reduce instances of research fraud and the waste of resources in academic research, will substantially strengthen the enterprise.

A key challenge for universities is deciding which decisions should be made by the central administration and which should be made in a more decentralized fashion by the faculty.

Decisionmaking Practices. A key challenge for universities is deciding which decisions should be made by the central administration and which should be made in a more decentralized fashion by the faculty. University administrators and faculty both bring valuable assets to the table. Administrators are skilled in balancing a variety of institutional goals. Faculty offer the necessary quality of creativity in their technical disciplines.

While decentralized, faculty-based decisionmaking is preferable as a general strategy, other approaches may be necessary under special circumstances. For example, if the range of funding mechanisms and sponsors becomes overly complex, or if funding itself levels off, a shift to more centralized decisionmaking across the institution may be desirable. In such cases, a major challenge will be to provide faculty with information about, and encourage their participation in, the institution's affairs, particularly in matters of research priority-setting.

In the years ahead, multi-disciplinary research teams will become more common as more complex topics emerge in science and technology. Universities will need to hire new research staff or establish new multi-departmental centers to provide support for these teams. New approaches to organization also will be required as collaborative research arrangements among industry, government, laboratories, and academia become more frequent.

In the years ahead, multi-disciplinary research teams will become more common as more complex topics emerge in science and technology. Universities will need to hire new research staff or establish new multi-departmental centers to provide support for these teams. New approaches to organization also will be required as collaborative research arrangements among industry, government, laboratories, and academia become more frequent.

Large-scale, multi-disciplinary research programs may require a more centralized, hierarchical type of management. This will allow strategic decisions and inter-departmental planning to be accomplished more effectively. Further, the increasing regulatory environment affecting several aspects of research (e.g., laboratory animals, carcinogenic substances, and radioactive materials) will often require institutional officials to participate in the selection of research topics and projects. Strong faculty participation in decisionmaking still will be essential, however. Effective communication and cooperation between institutional administrators and faculty is crucial to the success of all changes in academic management.

Non-departmental and Independent Centers. Special concerns may arise regarding the management of non-departmental and independent research centers. Research institutions may need to clarify their

expectations for faculty who work at such centers. For example, faculty obligations to their home departments should be distinguished from those to the non-departmental units that house their research laboratories.

When new centers are being established, universities may want to consider the effects of adding new administrative layers. New centers may be most effectively managed if they are administered and receive a similar degree of oversight as other comparable university functions.

Finally, research institutions may want to eliminate or redirect independent research centers or university-based federal laboratories that have lost their vitality or purpose. The more research institutions depend on these kinds of non-departmental arrangements for conducting research, the more the quality of their output will need to be monitored. Such centers may need to be periodically reevaluated to make sure they are placed within the institution where they will be most effective, to maintain their ties to traditional teaching functions, and to monitor the faculty reward systems.

The number and type of research consortia formed between or among colleges, universities and federal and industry research laboratories will increase in the next several decades. Just as for new centers, however, rigorous management standards and careful organization and planning will be required.

Consortial Arrangements. The number and type of research consortia formed between or among colleges, universities and federal and industry research laboratories will increase in the next several decades. Just as for new centers, however, rigorous management standards and careful organization and planning will be required. Consortia must not only be productive, but they also must support the other missions of universities.

The current organizational structure of research institutions also may need to change as industries increase their support for university-based research. Academic scientists and engineers will continue to be drawn to join industry research operations, either as consultants or as full-time employees. To adapt successfully to these new linkages and to the changing composition of their research staffs, research institutions will need to put in place flexible management and salary policies.

Flexibility will also be needed as research universities negotiate new arrangements with federal research laboratories. There are mounting pressures to make federal research facilities, especially those housing one-of-a-kind scientific instruments, available to the research community at large. In instances where this has already taken place, university consortia have been formed to manage these "shared resources." Such considerations will also apply to other consortial arrangements with non-federal laboratories.

Tenure Process. The practice of providing unlimited tenure for senior teaching faculty was originally instituted to protect freedom of speech and scholarly inquiry. Academic institutions in the future will need to develop ways to protect such freedoms for their teaching faculty, while at the same time being responsive to rapid

change in the sciences and engineering. Universities and colleges with major research programs may consider instituting modified tenure arrangements for certain research faculty appointments in the sciences and engineering.

While any change in the tenure system will be difficult, one such option would be to appoint research faculty to annually renewable, multi-year terms, an approach already taken by several institutions for non-faculty research personnel. Such "rolling tenure" contracts might give institutions the flexibility to refocus their research programs, while at the same time providing some protection to faculty and staff whose terms are not renewed.

ADAPTING TO SOCIETAL CHANGE

Universities, government agencies, and professional scientific and engineering organizations will need to consider the implications of societal and demographic change for the nation's research enterprise.

Societal and demographic changes occurring in the United States are increasingly reflected within the research enterprise. Academic institutions are faced with declining numbers of students who are interested in science and engineering and the additional but related problem of inadequate pre-college preparation in mathematics and the sciences. Women and minorities constitute a growing share of student enrollments in higher education, yet both groups are currently under-represented as educators, researchers, academic officers, and policymakers in the sciences and engineering.

Younger scientists and engineers bring different sets of experiences and often different expectations to their jobs than do more established researchers. Women and minority, faculty may have cultural values that differ from the majority of U.S. researchers, who are predominantly white males of European descent. The increasing phenomenon of two-income households has changed the personal-support network for many research faculty. With both parents working, child-rearing responsibilities are being shared more equally. In addition, longer commutes for faculty at campuses in large urban areas, combined with increased family responsibilities, exert pressures to adopt work hours similar to other occupations.

Universities and funding agencies must adopt appropriate policies and programs in response to societal and demographic change.

Universities and funding agencies must adopt appropriate policies and programs in response to societal and demographic change. To address the declining number of students who are interested in science and engineering, immediate and concerted action by all educational institutions will be needed to encourage qualified students, especially women and minorities, to pursue coursework in the sciences and engineering.

In response to changing family and personal demands of younger investigators, universities need to institute "flexible workplace" policies and programs. These might include hiring, promotion, and tenure policies that

take into account interruptions or slowdowns in the progress of an academic researcher's professional career, and policies that allow for temporary, part-time employment or extended leaves of absence.

The academic research community will need to engage in extensive dialogue about the changing expectations and cultural values of younger researchers. Such a dialogue should address the implications of societal and cultural change for the research agenda in the various disciplines and for the conduct of research itself. Some argue that the research community will have to adapt to the changing culture, organization and personal styles of newer generations of academic investigators. Others, in contrast, suggest that new participants in the enterprise must become better "acculturated" within the traditional "culture of American science" that has evolved over the past century. Whichever approach is taken, the working group believes that several general principles guiding the conduct of research should not change. These include the maintenance of quality through peer review, the unrestricted flow of scientific information, replication of research re-suits, and publication in refereed journals.

REVITALIZING EDUCATION

In the future, research institutions will need to expend considerable effort to maintain or enhance the quality of science and engineering education at the undergraduate, graduate, and increasingly, at the pre-college level.

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Universities' dual missions of research and education are under increasing strain. The United States is unique in its primary reliance on universities for conducting basic research.[9] The distinguishing feature of U.S. academic research, the linkage of research and education, originated in the earliest American universities during the years following the Civil War. Over the past century, this coupling of functions has led to extraordinary success in the sciences and engineering.

Tensions within the university faculty community, however, have been growing because of recent changes in the research environment. More than ever, university-based research activities are dependent on external funding. Academic researchers are devoting increasing time and effort to obtaining research support. They also are coping with new state and federal regulations that affect the conduct of research. As a result of these and other factors, faculty involved in research generally have less time not only for research, but also for teaching and public service.

Universities need to improve the quality of science and engineering education, especially at the undergraduate level. Colleges and universities will have to take their teaching responsibilities very seriously and put as much creative effort into curricula planning and undergraduate teaching as is put into their research programs. Undergraduate students within research universities often benefit from being in contact with investigators working at the frontiers of science and, in the best of circumstanc

es, learn how research is really done. Furthermore, public support of institutions of higher education is strongly linked to public perceptions of the quality of the undergraduate teaching mission.

Academic research institutions face a dilemma as they try to improve their undergraduate programs. They must help their faculty, sustain active research programs that are an essential component of graduate education. At the same time, they must make sure that faculty, involved in research have enough time and incentives for high-quality undergraduate teaching.

University resources will have to be used effectively for undergraduate education, for developing new courses and for providing proper educational facilities and equipment. Attention will have to be given to preparing teachers and to providing opportunities for faculty to improve their teaching skills and course work.

The evaluation of teaching skills and of educational programs will become increasingly important. An accurate and fair method of assessing teaching skills will be necessary. Local faculty, peer groups, and current and former students, should take part in this assessment process.

With respect to graduate education, although the average time-to-degree for PhDs has not increased in the natural sciences and engineering as much as it has in the social sciences and the humanities, the increase is costly and should be taken as an additional warning sign of serious problems in the science and engineering pipeline.[10]

The working group believes that a significant factor in the lengthening time-to-degree is inadequate funding for graduate fellowships and the direct costs of research. Students who are unsupported or only partially supported take longer to complete their degree. Similarly, students who are dependent for their research activities on under-funded research programs spend considerable time improvising what they could purchase, and waiting to buy from the following year's budget what they need today.

The availability of new academic employment opportunities and better information about industrial research careers would also encourage students to enter science and engineering graduate programs and, once enrolled, to work quickly to complete their degree.

With respect to pre-college education, the public increasingly is looking to the nation's institutions of higher learning for help in defining and organizing pre-college curricula. It should be emphasized that, except for schools of education, this is a new assignment for universities, and one for which they are poorly prepared at present. Over the last decade, numerous attempts by universities to improve pre-college science and mathematics education have been made. The result in some cases is that the best students have arrived at college better-prepared than in the past. This is particularly true of programs designed to attract and retain science and engineering students from previously under-represented groups. The situation is not as hopeful for the average student, however, who arrives at college less well-prepared than in the past.

STRATEGIC OPTIONS

Four large-scale forces—the pace and nature of research, economic conditions, political interests, and the international context will have important and powerful effects on the enterprise and, for the most part, are outside the direct control of those who conduct, fund, and oversee research in institutions of higher learning.

Ensuring the long-term health of university-based research—its overall quality, originality, productivity, diversity, and social usefulness—will require national policies, programs and resources appropriate to the changing characteristics of the enterprise. Desirable funding levels, required numbers of research personnel, and appropriate decision making mechanisms, for example, will in large part be dependent upon the evolving size of the enterprise and its changing structure—the degree of concentration or diversification of scientific and engineering academic research programs.

The overall size and structure of the enterprise, in turn, will be influenced by a number of large-scale forces which, for the most part, are outside the direct control of those who conduct, fund and, oversee research in institutions of higher learning. All participants in the U.S. research system need to understand these forces and how they may affect the academic enterprise in the future.

The working group developed its own framework for organizing these complex and often subtle issues. (See box on page 26.) First, it identified the large-scale forces it believes will have the most profound impact on the future of academic research.

Second, the working group considered the effects these forces might have on the size and structure of the enterprise. A set of hypothetical "scenarios" for the future of U.S. academic research was developed to illustrate these concepts. Third, the working group considered the long-term consequences of moving toward each scenario. Finally, the working group identified key policy or programmatic requirements, specific to each scenario, that would have to be met to maintain the health of the enterprise in the decades ahead.

The rapidly growing array of new scientific and technological opportunities and challenges is inexorably pushing the enterprise toward expansion. These opportunities and challenges arise both from within the research community and from society at large.

LARGE-SCALE FORCES

The working group identified four large-scale forces—the pace and nature of research, economic conditions, political interests, and the international context—that it believes will have important and powerful effects on the enterprise.

The Pace and Nature of Research

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A FRAMEWORK FOR NATIONAL-LEVEL STRATEGIC THINKING

1. Understanding the large-scale forces that shape the enterprise:

• the *pace and nature of research*, which lead both to rapid changes in the research agenda and to increasing complexity in the organization and conduct of research
• *economic realities* confronting the united states over the next decades, including expected constraints on funding for meeting national needs
• *political interests* in scientific and technological progress at the local, regional, and national levels, which ultimately determine the allocation of public resources in research
• *the international context* within which the enterprise must function, particularly with regard to the united states' economic, political, and military relationships with other nations

2. Projecting alternative scenarios

• size of the enterprise: expansion, steady-state, or down-sizing
• structure of the enterprise: more concentrated, current configuration, or more diversified.

3. Considering long-term consequences

• research capacity
• response to new opportunities
• human and financial resources
• organization of decisionmaking

4. Formulating policy requirements

• human resources
• financial resources
• locus of decisionmaking
• communications infrastructure
• openness of global research system

Genetic engineering, for example, now over 10 years old, has its roots in earlier genetic research conducted during the 1930s and 1940s, and the determination of the structure of DNA and the elucidation of the genetic code in the 1950s and 1960s, respectively. The vigorous pursuit of these discoveries has led to dramatic advancements in many fields of biology and medicine. Similarly, the study of the solid state nature of materials led to the development of transistors, which are now fundamental components of most electronic devices. More recently, molecular modelling is allowing biochemists and pharmacologists to construct new, potentially useful drugs.

Societal demands for solutions to many urgent problems also tend to increase the size of the enterprise. For example, the biomedical research

community was mobilized in the early 1980s when the threat of AIDS became apparent. Congress appropriated additional monies and agencies re-directed existing funds for basic research on the AIDS retrovirus, for drug development, and for prevention. A large cadre of researchers began to specialize in AIDS-related research. These developments were the result of the need to confront a severe epidemic, rather than a logical and orderly extension of ongoing research. Yet, as a consequence, new research avenues are rapidly emerging in the fields of virology, immunology, and genetics.

Recently identified global environmental problems have prompted significant additional investments in research by a number of countries. The need to learn about the causes and consequences of such phenomena as acid rain and global warming will most likely increase the numbers of investigators in relevant scientific and engineering fields.

The increasingly complex nature of research will affect the size and organization of research institutions. Larger and more multi-disciplinary research teams will be necessary for addressing many topics in science and technology. It is not clear whether these teams will be located most appropriately at large institutions with broad-based research portfolios, or among groups of smaller, more narrowly focused research institutions.

The desirable work environment of researchers in the next century is also unclear. The preeminent researchers of the future may need to be more specialized than today's investigators, relying more on cooperative relationships with their peers. On the other hand, to be highly successful, tomorrow's scientists may have to be fiercely independent, isolating themselves at times from the enormous flood of information that flows over modern communication systems.

. . . a large and growing national economy would more readily accommodate an expanding research enterprise. Conversely, over the long term, a weak or declining economy would most likely make it difficult to sustain even the current level of research activity in the United States.

Economic Conditions

The strength of the U.S. economy will be an important factor in setting the overall level of resources available for meeting national needs. In this respect, a large and growing national economy would more readily accommodate an expanding research enterprise. Conversely, over the long term, a weak or declining economy would most likely make it difficult to sustain even the current level of research activity in the United States.

Academic research institutions will thus have an increasing interest in the economic vitality of the nation. Their public support will be closely tied to the country's ability to generate wealth through increased industrial competitiveness and work-force productivity.

Universities and colleges involved in research contribute to the nation's economic growth through their role in educating a productive workforce and by creating new knowledge of potential commercial value. Additional economic benefits may result from the impact new or expanded research institutions have on local and regional economic growth.

For all of its economic benefit to the nation, however, academic research will be just one of many factors affecting the size and strength of the U.S.

economy. Industrial productivity, international trade, inflation, and employment also will come into play. Similarly, policies for U.S. research and development will be but one part of overall national economic policy. Fiscal, monetary, and trade policies will be other vital ingredients.

Furthermore, academic research institutions will benefit from a healthy economy only to the extent that the public believes in the social value of the work they perform. Taxpayers will provide substantial financial support for academic research only if there is convincing evidence that research is helping to maintain or improve the quality of life and the standard of living.

How well academic research fares in the political process will depend largely on public perception of the enterprise, and how these collective feelings are communicated to lawmakers.

Political Interests

In the decades ahead, the unpredictable cross-currents of the U.S. political process will exert a major influence on both the size of the overall research enterprise and its structure. The level and allocation of resources devoted to university-based research will be determined by political decisions made at the local, state, and national levels.

How well academic research fares in the political process will depend largely on public perception of the enterprise, and how these collective feelings are communicated to lawmakers. Supporting research remains a generally popular political position. Society's ability to accept and make use of advances in technology, and public understanding of the value of basic research, will be critical factors in future political support for university-based research.

Those who fund, conduct, and oversee academic research will be able to influence certain aspects of the political process. Opinions expressed by the scientific and engineering communities, for example, can affect decisions by legislators to appropriate funds for specific research projects.

The allocation of public funds to research institutions is affected by two powerful and sometimes conflicting national political objectives. The first is to support research of the highest quality. A second objective is to enhance the research capacity of individual states and regions.

Public spending, however, is a reflection of the priorities that the country places on addressing important national goals. As such, academic research will compete with other needs, such as rebuilding roads and bridges, addressing crime and poverty, assuring high-quality education and health care, and providing for the well-being of the elderly. While steady investments in academic research may very well contribute to the long-term solution of these problems, economic problems, such as deficits and recessions, tend to shorten national political perspectives and to encourage spending on short-term remedies. Academic research requires long-term financial commitment.

The allocation of public funds to research institutions is affected by two powerful and sometimes conflicting national political objectives. The first is to support research of the highest quality. To that end, Congress has authorized several federal agencies to disburse research dollars, which they do with the advice of outside experts. Most federal support for academic research today is allocated, at the project level, through such "peer review" processes.

A second objective is to enhance the research capacity of individual states and regions. At the national level, the growing federal contribution to ac

ademic research, approaching $10 billion in 1991, makes the research enterprise more visible politically and thus more subject to political apportionment. In the U.S. Congress, this is evident in the increasing number of non-peer-reviewed line-item appropriations for research facilities and programs at individual universities.

The notion that each state or region should possess a world-class institution of higher education and research has enormous political appeal. There is a generally strong belief that the presence of research universities contributes to regional economic well-being and competitiveness. As a consequence, numerous research programs and research facilities have been made possible by political initiatives launched or supported by individual legislators at the state or federal level. Several state governments have increased resources for building up their flagship campuses. The growth in leveraged local funding for research programs has also created research capacity at scores of universities previously devoted largely to teaching.

The extent to which U.S. investigators have access to frontier research conducted in other nations has major strategic implications for the academic research enterprise. A shift toward a more open international research system would give the United States greater flexibility in setting its overall research agenda.

International Context

In the first three decades following World War II, the United States provided most of the research infrastructure—equipment and facilities—for its own research requirements in academia, industry and government laboratories. The United States also granted much of the world's research community access to its research infrastructure.

As the research capability of other nations increases, however, such research instrumentation is now becoming more equally distributed among countries. Furthermore, as the cost of research infrastructure has increased rapidly, many expensive pieces of equipment are becoming scarce.

This occurs at a time when fierce economic competition is beginning to dominate the international arena. The political response of individual nations and multinational trading blocks could shift the world economy either toward greater openness and interdependence or toward more barriers to the free flow of information and goods. The outcome will have a profound impact on the future size and breadth of the U.S. research effort.

At stake are the ability and willingness of the growing international research community to exchange information and to collaborate in vital research areas. The extent to which U.S. investigators have access to frontier research conducted in other nations has major strategic implications for the academic research enterprise.

A shift toward a more open international research system would give the United States greater flexibility in setting its overall research agenda. The nation would have the option of targeting selected fields of vital strategic interest or those in which it has a comparative advantage. New communication technologies would facilitate collaboration between U.S. and foreign researchers in specific fields. Shared investments in "big-ticket" research instrumentation would become more attractive.

Whatever the international economic and political climate, achieving an open flow of research information may not be easy. This is primarily because of the structural differences among the research systems of different nations.

With greater access to foreign research at the frontiers of science and technology, the United States could explicitly decide not to invest in fields in which other countries have a commanding lead, or for which other nations have constructed expensive, one-of-a-kind research facilities not available here. The United States, of course, would still need to maintain a critical mass of expertise in "non-targeted" fields. Without this relatively modest investment, it would be difficult to take advantage of discoveries made abroad and to educate future generations of researchers in these fields.

At the other extreme, barriers to the international flow of research information would likely force the United States to seek research self-sufficiency in almost every field. This approach would require a significant expansion of the research workforce, including the recruitment of science and engineering talent from foreign countries. At the same time, it would necessitate greatly increased resources for research.

Such a massive mobilization of human and financial resources might well be economically or politically unrealistic and, consequently, the ability of the United States to remain a leader in science and technology might be jeopardized. In the long run, international policies that restrict the free flow of fundamental scientific information would be as destructive to this nation's strength as are trade wars.

Whatever the international economic and political climate, achieving an open flow of research information may not be easy. This is primarily because of the structural differences among the research systems of different nations. In the United States, for example, most basic research is conducted by university-based scientists and engineers. The results of that work are disseminated in publicly available journals and, increasingly, through electronic media. In many other countries, by contrast, frontier basic research in targeted fields is performed largely in government or industry laboratories, which also conduct a substantial amount of applied, proprietary research. There is a danger that, in response to growing international economic competition, the results of much foreign-based research may not be promptly or freely released to the public.

It is likely that other nations would resist a demand by the United States to make fully available the research output of their government or industry laboratories. If they were to comply, they probably would do so only if the results of research conducted in U.S. government and industry laboratories were made available. In the short term, this uncomfortable and improbable quid pro quo might be the only way of ensuring a fair exchange of basic research information among countries.

In the long term, an international convergence of national research systems, toward more equitably funded, publicly available research institutions, may help resolve the problem. In the meantime, tensions among national governments, brought about by the differences among the research systems, are likely to continue.

In the long term, an international convergence of national research systems, toward more equitably funded, publicly available research institutions, may help resolve the problem. In the meantime, tensions among national governments, brought about by the differences among the research systems, are likely to continue.

At the level of individual investigators and research projects, however, new communication technologies will facilitate greater worldwide exchange of information, independent of the international economic or political climate. Such interactions will become a pervasive feature of the international research community in the next century.

In the past, major international crises such as wars, political turmoil, or foreign technological breakthroughs served to strengthen U.S. university-based research. For example, the rise of National Socialism in Germany during the 1930s stimulated a stream of emigration by eminent European scientists, many of whom assumed professorships at U.S. universities. World War II and the Soviet launch of Sputnik led to dramatic increases in public funding of U.S. science education and university-based research. Future international crises, especially those involving national technological advantages, could also have a profound influence on public support for U.S. university-based research. While unpredictable, the possibility of such events must be factored into scenarios for the future.

ALTERNATIVE SCENARIOS

The pace and nature of research, economic conditions, political interests, and the international context will shape the character of the U.S. aca

SIZE OF THE ENTERPRISE

An expanded academic research enterprise could result from strong growth in national economic wealth, from political decisions to increase public investments in academic research to achieve social goals, or from political decisions to shift national basic research funding toward academic institutions. Rising international research competition could result in increased financial support to maintain U.S. preeminence in science and technology. The quickening pace of research opportunities would be expected to exert continuous pressure toward expansion.

A steady-state academic research enterprise could result from moderate national economic growth, from political decisions to sustain moderate increases in public investments for research, or from political decisions to augment basic research activities in non-academic institutions.

A down-sized academic research enterprise could result from reduced national economic capacity to support research, political decisions to shift public investments toward sectors other than research, political decisions to augment substantially the basic research activities of non-academic institutions, or university decisions to ensure the quality of their research activities at the expense of quantity. An open flow of international scientific and technological information could possibly allow, but not necessarily result in, a smaller U.S. enterprise.

demic research enterprise into the next century. These forces will be felt primarily in terms of the size and structure of the enterprise.

STRUCTURE OF THE ENTERPRISE

Under any plausible scenario, the U.S. academic research enterprise will continue to be composed of a wide diversity of research institutions, ranging from those with broad-based research portfolios to those with narrowly-focused programs. The following is a discussion of possible relative shifts in the overall composition of the enterprise, toward either larger-scale or smaller-scale research institutions.

A more concentrated academic research enterprise could result from judgments that institutions with a broad array of research programs could best address emerging research opportunities. Depending upon funding allocation methods, fluctuating or rapidly shifting national investments in research could, over time, promote universities with broad research portfolios. Such a shift could also result from successful efforts by aspiring institutions to broaden the scope of their research activities or from public policies and programs to enhance broad-based, "world class" U.S. research institutions.

The current structure of the enterprise might be maintained if national and state research funding policies remain unchanged and all research institutions were able to obtain continued financial support from a multiplicity of sources.

A more diversified academic research enterprise could result from judgments that institutions that concentrate their human and financial resources within fewer areas of research strength would be best able to address emerging research opportunities. Depending upon funding allocation methods, fluctuating or rapidly shifting national investments in research could, over time, promote institutions with narrower research portfolios. Political decisions could also result in broadened geographic or institutional distribution of the nation's research capacity. Increased use of telecommunications could facilitate greater dispersion of research personnel within institutions across the country.

During the next several decades, the size of the U.S. academic research enterprise—the number of academic departments and research personnel—may grow, remain in steady-state, or become smaller. (See box on page 31.) It would be possible to have a larger enterprise without creating more research institutions, if the number of departments or personnel within the existing set of institutions were to increase. Similarly, a smaller enterprise could be envisioned while retaining the current number of institutions, if the number of departments or personnel in existing universities were reduced. Independent of the overall size of the enterprise, the distribution of talent and resources among research fields may change.

The structure of the academic research enterprise, expressed as the degree of concentration or diversification in science and engineering talent

among research institutions, also could change over time. (See box on page 32.) The enterprise could become more concentrated within universities recognized for their scientific strength in a broad array of fields. Alternatively, the enterprise could become more diversified, with a dispersion of the nation's academic research activity among institutions with a focus on fewer research fields or sub-fields. This could be accomplished if current large-scale research universities reduced their research portfolios, or if aspiring research universities developed one or more nationally-recognized research programs, or by both factors.

Within this framework, there are nine possible combinations of size and structure. (See box on page 33.) These combinations should be viewed as points on a plane, not as rigid endpoints where U.S. academic research will one day come to rest. These hypothetical shifts in the direction of the enterprise are further characterized as qualitative "scenarios" for the future of U.S. academic research. (See Figure 6 on page 34.) The scenarios are a way of thinking strategically about the different directions in which the four large-scale forces could push the enterprise. (See Tables I-III, pages 35-37.)

ALTERNATIVE SCENARIOS

Expansion Scenarios

- *Integrated Expansion*: larger enterprise concentrated within universities with broad research portfolios.
- *General Expansion*: larger enterprise within the current configuration of research institutions.
- *Diversified Expansion*: larger enterprise distributed across a greater number of more narrowly focused research institutions.

Steady-State Scenarios

- *Consolidation*: current-size enterprise increasingly concentrated within universities with broad research portfolios.
- *Status Quo*: current-size enterprise within current configuration of research institutions.
- *Dispersion*: current-size enterprise distributed across a greater number of more narrowly focused research institutions.

Down-Sizing Scenarios

- *Concentration*: smaller enterprise concentrated within universities with broad research portfolios.
- *General Contraction*: smaller enterprise within the current configuration of research institutions.
- *Decentralization*: smaller enterprise distributed across more narrowly focused research institutions.

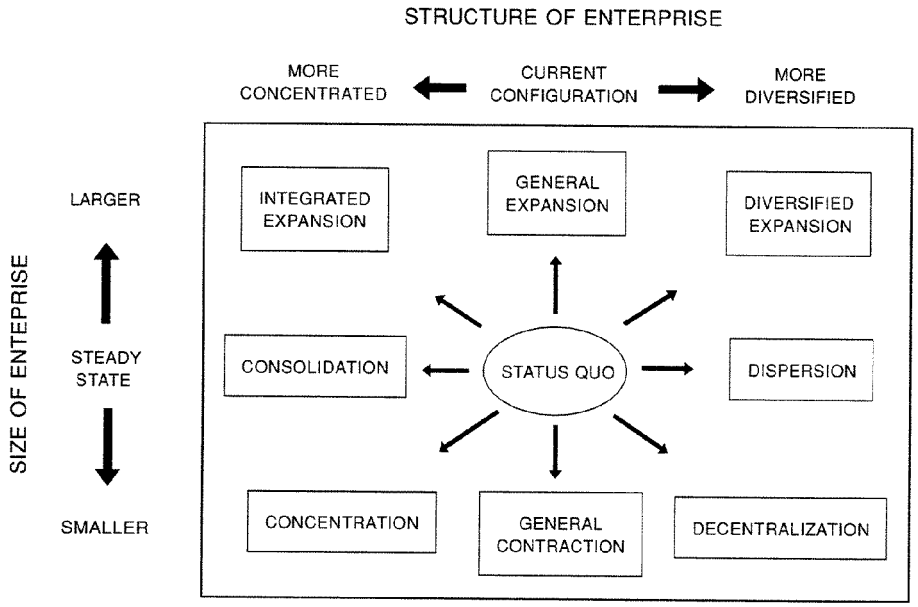

FIGURE 6
Scenarios for the 21st Century

TABLE 1 Expansion Scenarios

INTEGRATED EXPANSION	GENERAL EXPANSION	DIVERSIFIED EXPANSION
A larger enterprise, in both numbers of researchers and active departments, within universities with broad research portfolios.	A larger enterprise, in both numbers of researchers and active departments, with comparable increases in both large-scale universities and aspiring research institutions.	A larger enterprise, in both numbers of researchers and active departments, distributed across a greater number of institutions with more narrowly focused research portfolios.
Forces Leading to Scenario	**Forces Leading to Scenario**	**Forces Leading to Scenario**
Pace and Nature of Research: Rapidly developing research opportunities thought to be best addressed by an expanded enterprise. Large-scale research universities most able to accommodate complexities of contemporary research.	*Pace and Nature of Research*: Rapidly developing research opportunities thought to be best addressed by an expanded enterprise.	*Pace and Nature of Research*: Rapidly developing research opportunities thought to be best addressed by an expanded enterprise. More narrowly focused research institutions best able to manage the complexities of contemporary research.
Economic Conditions: A robust, expanding national economy supports a larger enterprise.	*Economic Conditions*: A robust, expanding national economy supports a larger enterprise.	*Economic Conditions*: A robust, expanding national economy supports a larger enterprise.
Political Interests: A political decision is made to in crease national investments in research. Ambitious regional and aspiring universities develop broad research portfolios through the success of political efforts launched at the local, state and national levels. Alternatively, or concurrently, federal policies shift to favor the support of greater numbers of "world class" research universities.	*Political Interests*: A political decision is made to increase national investments in research. The number of aspiring research institutions continues to increase as do the number of large-scale research universities, reflecting the political push for wider geographic and institutional distribution of resources and talent.	*Political Interests*: A political decision is made to increase national investments in research. To broaden the national research base, federal policies favor redistributing research support across a greater array of institutions. Requirements for cost-sharing promote entrance into the research enterprise by institutions with limited current investments in research.
International Context. Growing international research competition increases U.S. support of research to maintain international standing.	*International Context*: Growing international research competition increases U.S. support of research to maintain international standing.	*International Context*: Growing international research competition increases U.S. support of research to maintain international standing.

TABLE 2 Steady-State Scenarios

CONSOLIDATION	STATUS QUO	DISPERSION
An enterprise of the current size, in both numbers of researchers and active departments, increasingly concentrated within universities with broad research portfolios.	An enterprise of the current size, in both numbers of researchers and active departments, within the current configuration of research institutions.	An enterprise of the current size, in both numbers of researchers and active departments, distributed across a greater number of more narrowly focused research institutions.
Forces Leading to Scenario	**Forces Leading to Scenario**	**Forces Leading to Scenario**
Pace and Nature of Research: The rapid development of research opportunities requires that the size of the current enterprise be maintained. Large-scale research universities best able to address the increasingly complex nature of research.	*Pace and Nature of Research*: The rapid development of research opportunities requires that the size of the current enterprise be maintained.	*Pace and Nature of Research*: The rapid development of research opportunities requires that the size of the current enterprise be maintained. More narrowly focused research institutions best able to manage the complexities of contemporary research.
Economic Conditions: A modestly growing national economy supports current size enterprise.	*Economic Conditions*: A modestly growing national economy supports current size enterprise.	*Economic Conditions*: A modestly growing national economy supports current size enterprise.
Political Interests: A shift in federal policies focuses long-term support on selected "world class" research universities. Regional and aspiring universities, due to low "critical mass" of research efforts, the increasing costs of research, and the increasing competition for top-level research talent, become less active participants in the enterprise.	*Political Interests*. The political push for wider geographic and institutional distribution of resources and talent is abandoned. Aspiring research universities are unable to grow further.	*Political Interests*: In order to broaden the national research base, federal policies call for a redistribution of research support across a greater number of institutions. Cost-sharing promotes entrance into the research enterprise by institutions with limited current investments in research.
International Context: Growing international research cooperation allows U.S. to maintain international standing with current size enterprise.	*International Context*: Growing international research cooperation allows U.S. to maintain international standing with current size enterprise.	*International Context*: Growing international research cooperation allows U.S. to maintain international standing with current size enterprise.

TABLE 3 Down-Sizing Scenarios

CONCENTRATION	GENERAL CONTRACTION	DECENTRALIZATION
A smaller enterprise, in both number of researchers and active departments, concentrated within universities with broad research portfolios.	A smaller enterprise, in both numbers of researchers and active departments, with comparable decreases in both large-scale universities and aspiring institutions.	A smaller enterprise, in both numbers of researchers and active departments, distributed across institutions with more narrowly focused research portfolios.
Forces Leading to Scenario	**Forces Leading to Scenario**	**Forces Leading to Scenario**
Pace and Nature of Research: Increasingly complex nature of research determined to be best addressed by broad-based universities.	*Economic Conditions*: A weakened national economy no longer is able to support an enterprise of the current size.	*Pace and Nature of Research*: More narrowly focused research institutions best able to manage the complexities of contemporary research.
Economic Conditions: A weakened national economy no longer is able to support the current enterprise.	*Political Interests*: Independent of the economic climate, a political decision is made to shift national resources away from research to other national needs. Political conflict continues between those who wish to support a core national research base and those who desire distribution of resources to wider array of institutions.	*Economic Conditions*: A weakened national economy no longer is able to support an enterprise of the current size.
Political Interests: Independent of the current economic climate, a political decision is made to shift national resources away from research to other national needs. To maintain a core national research base, federal policies shift to focus long-term support on selected "world class" research universities.	*International Context*: Growing global research system, with open access across borders, allows U.S. to target selected fields of vital strategic interest.	*Political Interests*: Independent of the economic climate, a political decision is made to shift national resources away from research to other national needs. To broaden the national research base, federal policies call for a redistribution of research support among institutions.
International Context: Growing global research system, with open access across borders, allows U.S. to target selected fields of vital strategic interest.		*International Context*: Growing global research system, with open access across borders, allows U.S. to target selected fields of vital strategic interest.

LONG-TERM CONSEQUENCES

The consequences of the enterprise moving in a given direction are profound, in terms of the overall capacity of U.S. academic research, the resources required to support the enterprise, and the organization of decisionmaking.

Expanding the research enterprise would offer the United States greater capacity for addressing new scientific and technological opportunities. Maintaining a steady-state enterprise would barely sustain the current national research capacity. Down-sizing the enterprise would mean surrendering many ongoing research areas in favor of opportunities of paramount national importance.

Expanding the research enterprise would offer the United States greater capacity for addressing new scientific and technological opportunities. With an increasing number of talented research personnel, this country could be more responsive to future challenges to our economy, health, environment, and national defense. To sustain such growth, however, would require a bold national commitment to enhancing our scientific and technological base. Given the rising costs of conducting research, the nation would have to dramatically increase its investments in research facilities, equipment, graduate education, and individual research projects. Given the problems of the U.S. educational system, science and mathematics programs at all educational levels would have to be improved substantially. Without such a long-term national commitment, expanding the enterprise would further exacerbate current tensions and ultimately damage the quality and productivity of U.S. academic research.

Maintaining a steady-state enterprise would barely sustain the current national research capacity. Reallocation of resources and re-deployment of personnel would be the major way new research opportunities and social needs would be addressed. Given the certain expansion of the worldwide research agenda, national decisionmaking would focus on the choice between new opportunities and ongoing research. However, maintaining the current number of research personnel throughout the coming decades would not imply a similar steady-state in financial resources. Given rapidly rising research costs, the enterprise would decline if increased real investments were not forthcoming. Likewise, given students' declining interest in science and mathematics, a significant improvement in the quality of science education would be absolutely essential.

Down-sizing the enterprise would mean surrendering many ongoing research areas in favor of opportunities of paramount national importance. Several serious consequences of such a transition need to be considered. First, the United States would increasingly become dependent on the science and technology of other nations. As described earlier, access to foreign science and technology may be thwarted by international political and economic rivalries and by the structural asymmetries of national research systems. Second, given the rising costs of research, even a down-sized enterprise would require at least sustained current real levels of research funding. Third, for a smooth transition to a smaller enterprise, explicit funding criteria for choosing among research fields would have to be established.

A shift toward a more concentrated research enterprise would, in general, allow for greater national decentralization of decisionmaking to universities and their academic departments. Coordinated planning of research activ

ities within each university would more likely result in a comprehensive national research portfolio. However, a down-sized enterprise condensed into a smaller set of "elite" research universities would, in time, most likely become a system of "national universities," resulting in increased decision-making authority at the federal level.

A shift toward a more concentrated research enterprise would, in general, allow for greater national decentralization of decisionmaking to universities and their academic departments. A shift toward a more diversified academic research enterprise would encourage research institutions to focus their resources within areas of research strength and achieve the political goal of a broader institutional and geographic distribution of the nation's research capacity.

A shift toward a more diversified academic research enterprise would encourage research institutions to focus their resources within areas of research strength. It would achieve the political goal of a broader institutional and geographic distribution of the nation's research capacity. With fewer research programs, however, individual universities would become more vulnerable to shifts in federal funding priorities than if they had broader research portfolios. Institutional decisions to reduce the number of research fields thus entail new risks to universities and to important parts of the academic research enterprise. In addition, significant investments in communications technologies would be essential to allow information exchange and research collaboration among investigators in geographically distant regions.

A down-sized enterprise, simultaneously becoming more diversified, would require new mechanisms for setting national research priorities. This would be needed both to coordinate widely dispersed activities and to ensure there were no important gaps in the nation's research portfolio. This scenario would be the most problem-ridden for individual U.S. investigators. Not only would it reduce the number of research fields, but the universities' central administrations would have to play the precarious role of deciding which research fields to abandon and which to reinvigorate.

POLICY REQUIREMENTS

For each scenario, a unique set of complementary policies and programs is required.

A critical challenge for decisionmakers will be to preserve the health of the academic enterprise—its quality, originality, productivity, diversity, and social usefulness—and the United States' standing in the international scientific and technological community. Regardless of the overall direction of the enterprise, U.S. policies and programs must encourage new generations to pursue careers in the sciences and engineering, ensure adequate funding, improve research-related decisionmaking, implement new communication technologies, and facilitate participation in the global research system.

The relative importance of any one of these policies, however, differs according to the size and structure of the enterprise. For each scenario, a unique set of complementary policies and programs is required. (See Figure 7 on page 40.)

Human Resources

If the U.S. academic research enterprise grows significantly larger, the need for more science and engineering personnel will become critical. This requirement is the same for all growth scenarios, regardless of whether the

structure of the enterprise is more concentrated or more diversified. (See Figure 8, page 41.)

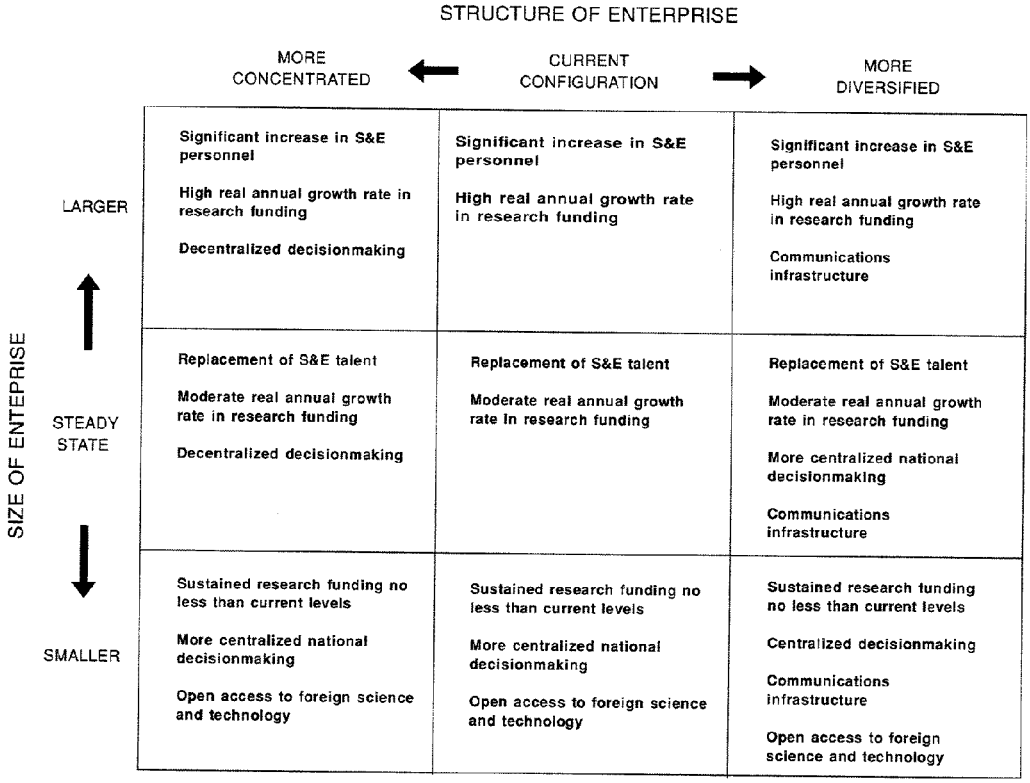

FIGURE 7
Scenario Policy Requirements

The United States has two primary sources for enlarging the pool of available research expertise. The first and most desirable is the nation's own citizenry. Successful efforts would have to be made to attract larger numbers of students, including women and minorities, into post-secondary science and engineering education, and to promote their subsequent participation in the research enterprise.

At the graduate level, significantly increased financial support would be needed in the form of stipends, fellowships, and assistantships. At the pre-college level, substantial improvements in science and mathematics programs would be required. This would necessitate dramatic improvements in student attitudes toward science and mathematics. For many, it also would

demand a fundamental recognition of the value of long-term investment in science and education.

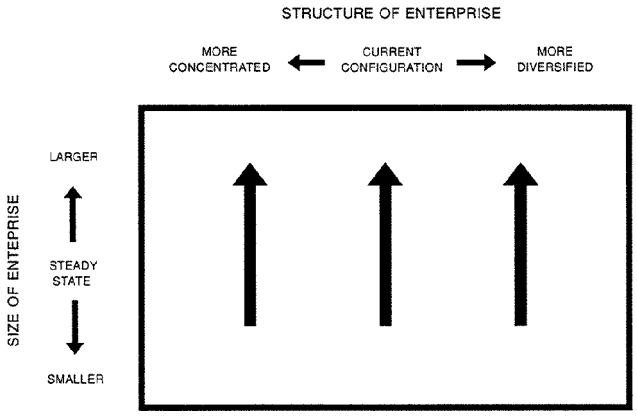

FIGURE 8
Human Resource Requirements

The second source of talent would be the potentially large number of foreign-trained scientists and engineers desiring to work in American research institutions. However, reliance on this source is risky. As described earlier, other countries, including many developing nations, are creating their own research systems that will compete directly with the United States for this pool of talent. As other nations increase their dependence on technology and science and face shortages of skilled workers, the competition for human skills is likely to increase.

Financial Resources

Should research costs per investigator continue to rise at a rate higher than general inflation in the economy, maintaining a steady-state in the size of the enterprise will require annual real increases in financial support for research projects, facilities, and equipment, as well as for graduate education. If such investments are not forthcoming, the enterprise would likely decline in both quality and capacity.

With rapidly increasing costs, expanding the number of researchers would require substantial real annual increases in funding for university-based research. In an expanding enterprise composed of more large-scale research universities, even greater funding growth would be required to support added duplication of programs across the enterprise. (See Figure 9, page 42.)

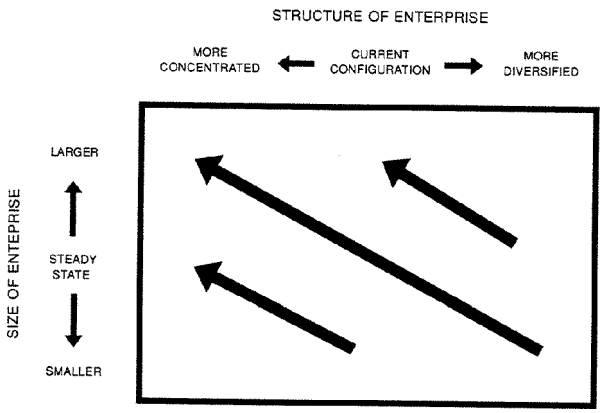

FIGURE 9
Funding Requirements

The plausibility of any funding level must be considered within the larger context of national economic growth and political willingness to increase public investments in research. In addition, political decisions to augment university-based research, relative to other research sectors, will also be a factor. If federal laboratories were to assume increased responsibility for costly research facilities and expand access to these facilities by university researchers, a growing academic research enterprise would be more possible. On the other hand, should federal laboratories more actively compete with academic institutions for basic research funding, growth in the academic sector may be more difficult.

Locus Of Decisionmaking

Decisions to add or terminate academic research programs, as well as to allocate funds for research infrastructure, currently are made at different levels. The locus of decisionmaking will depend on the changing size and structure of the enterprise. (See Figure 10, page 43.)

If the enterprise were to become more concentrated within large-scale research universities, decisionmaking might best take place at the institutional and departmental levels rather than the national level, because of the breadth of coverage within each university.

If the enterprise were to become more diversified, there would be greater need for national-level decisionmaking to coordinate widely dispersed activities. If the enterprise were simultaneously shrinking in size, new na

tional decisionmaking mechanisms would be absolutely required to ensure that no important gaps occur in the nation's research portfolio.

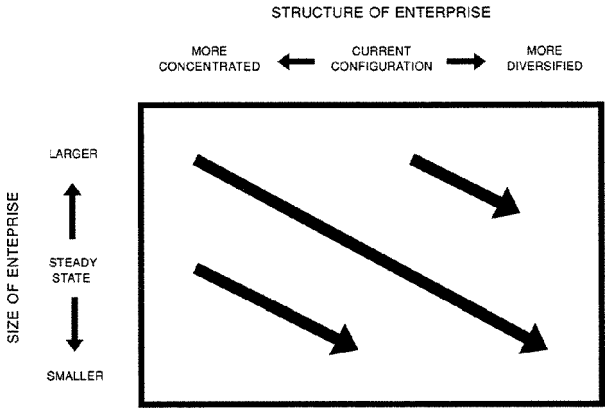

FIGURE 10
Shift Toward National Decisionmaking

In an enterprise comprised of more research institutions with limited research portfolios, there also would be greater need for decisionmaking at the level of the central administration of each institution. If these universities were to reduce the number of their research fields, more centralized decisionmaking would become a necessity during the transition.

Communications Infrastructure

The conduct of research at all levels is becoming increasingly dependent on telecommunications technologies. Contemporary research problems are being addressed by larger and more complex teams of investigators around the world. In many instances, sophisticated and more expensive research equipment is needed. Telecommunications networks allow widely dispersed research personnel to share data, to collaborate effectively, and to use one-of-a-kind research instrumentation.

If the enterprise were to become more diversified across a broader array of institutions, an effective national telecommunications infrastructure would be absolutely essential. A key component of the infrastructure would be personal computers used as "information ports" to receive and send electronic and voice mail, complex documents, and real-time video images; to access specialized databases and digital libraries; and to perform experiments

using advanced supercomputers, automated research instruments and other modern facilities in remote locations. (See Figure 11, page 44.)

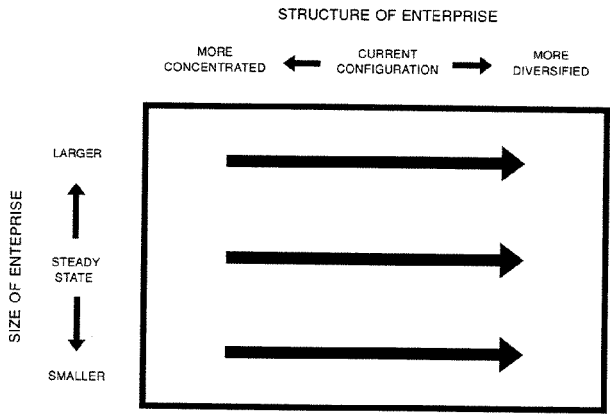

FIGURE 11
Requirements for Communication Technologies

Openness Of The Global Research System

Whatever the size of the U.S. academic enterprise, access to foreign sources of new knowledge and technology will be essential. This will be especially critical as the research systems of other nations grow and become more effective.

If the U.S. enterprise were to shrink over the next several decades, access to foreign research would become absolutely essential for maintaining the overall quality and usefulness of academic research in this country. (See Figure 12, page 45.) In this situation, the United States would have to have full access to the results of basic research conducted by other countries. Unlike the requirements for funding, human resources, decisionmaking, and the use of telecommunications technology, however, the openness of the global research system depends upon decisions made within many nations.

Evaluating Specific Policy Proposals

Policymakers must carefully consider the consistency and efficacy of policy proposals affecting human and financial resources, locus of decision-making, communication infrastructure, and openness of the global research system. The proposals must be evaluated in terms of their explicit and im

plicit objectives, assumptions about the size and structure of the overall enterprise, plausibility of complementary policy requirements, and implications for near-term decisionmaking. (See box on page 46.) Inconsistent policies, programs, and resource commitments will lead to chaotic conditions and will have a potentially disastrous effect on the quality of academic research in this country.

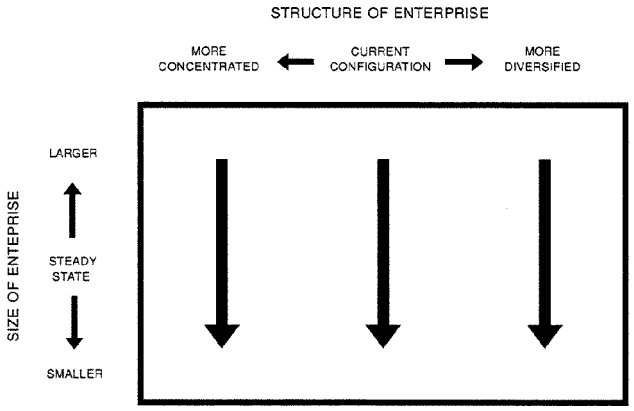

FIGURE 12
Required Access to Foreign Research

A FRAMEWORK FOR CONSIDERING POLICY PROPOSALS

The evaluation of long-term research policy proposals would be improved by addressing the following questions about the proposals:

1. **What are the explicit and implicit objectives? [e.g., improving the capacity, quality, productivity, diversity, or social usefulness of academic research.]**
2. **What are the assumptions regarding the overall enterprise?**

a. The direction of the enterprise? Implications for achieving policy objective?

- size of enterprise: growth, steady-state, or downsizing
- structure of the enterprise: more concentrated, current configuration, or more diversified

b. What external conditions are required to achieve that direction? Are they plausible?

- trends in the pace and nature of research
- economic realities
- political interests
- the international context

c. What are the concomitant policy requirements? Are they plausible?

- human resources
- financial resources
- locus of decisionmaking
- communications infrastructure
- openness of global research system

3. **What are the implications for near-term decisionmaking?**

- setting priorities
- intersectoral funding responsibilities
- institutional organization and management
- adapting to societal change
- institutional educational mission

FATEFUL CHOICES

The research enterprise of the future will be unlike the one of today. Two visions of the future stand in stark contrast: a more hopeful vision in which the research enterprise sustains leadership within the emerging global research system, provides opportunities for young talent within a diverse population, takes best advantage of frontier technology, and contributes to the vitality and well-being of this country; and a less-hopeful one, in which there is unproductive competition within the research community, an inability to pursue research opportunities of critical importance to the United States, and a gradual decline in international preeminence.

Achieving the more positive vision will require making difficult choices with potentially fateful consequences for the research enterprise.

NEAR-TERM DECISIONS

Unless the U.S. research community adequately responds to changes now occurring within the enterprise, harmful tensions will persist and public support will erode.

Unless the U.S. research community adequately responds to changes now occurring within the enterprise, harmful tensions will persist and public support will erode.

Priority-Setting. Without clearer priority-setting, there will be increasing confusion about and less than optimal investments in frontier research and in the research infrastructure of vital importance to the nation.

Funding Responsibilities. Without a clearer division of funding responsibilities, the essential needs of the enterprise—people, equipment, infrastructure—will not be met.

Organization and Management. Without innovative organizational and managerial adaptation, research sponsors and universities will be less responsive to emerging research challenges and opportunities.

Societal Change. Without successful adaptation to social change, the research environment will be less responsive to the aspirations of succeeding generations of investigators.

Education. Without revitalized educational programs, universities will fail to nurture technically literate students and future generations of scientists and engineers, and, as a result, will gradually lose public support.

STRATEGIC OPTIONS

Strategic decisions that will determine the future size and structure of the enterprise will be made in this country, either deliberately or inadvertent

ly. These choices will influence the capacity and structure of research in the United States for decades to come.

It is crucial that these choices be made comprehensively and explicitly. Inaction would be the worst possible choice.

Future Size of the Academic Research Enterprise. The choice ahead is whether to increase, sustain, or decrease the national research capacity. The first option is to facilitate greater national capacity for addressing new scientific and technological opportunities. The second option is to reallocate resources and re-deploy personnel as the major modes of addressing new research opportunities and for meeting social needs. The third option is to curtail many ongoing research areas in favor of selected opportunities of paramount national importance and to rely on increased access to the science and technology of other nations.

Future Structure of the Academic Research Enterprise. The choice ahead is whether to concentrate research programs within large-scale research universities, retain the current configuration, or diversify the enterprise across more narrowly focused research institutions. The first option is to enhance "world class" U.S. universities with broad research portfolios. The second option is to maintain the current mix of policies which support both large-scale and aspiring research institutions. The third option is to encourage universities to concentrate their resources within selected areas of research strength and to distribute national research capacity across a wider array of institutions and geographic regions.

These choices are interdependent and will be affected by the complex interplay of large-scale societal forces and specific policy requirements. Inconsistent or contradictory policies will have a decidedly harmful effect on the quality and productivity of U.S. academic research. Thus it is crucial that these choices be made comprehensively and explicitly. Inaction would be the worst possible choice.

Notes

1. Government-University-Industry Research Roundtable, *Science and Technology in the Academic Enterprise: Status, Trends and Issues*, Washington, D.C.: National Academy Press, October 1989.
2. For a review of issues and data regarding the costs of research and proposal success rates, see U.S. Congress, Office of Technology Assessment, "Understanding Research Expenditures," in *Federally, Funded Research: Decisions for a Decade*, (OTA-SET-490), Washington, D.C.: U.S. Government Printing Office, May 1991, pp. 171-201.
3. "Science: The End of the Frontier?" American Association for the Advancement of Science, January 1991.
4. Decisionmaking processes regarding priority-setting will need to be developed by the parties involved. For further discussion, see Part III, "Charting a New Course," pgs. 53-58.

5. For an example of such priority-setting, see National Research Council, *The Decade of Discovery in Astronomy and Radiophysics*, Washington, D.C.: National Academy Press, 1991.
6. For recommendations for national priorities within the biomedical research enterprise, see Institute of Medicine, *Funding Health Sciences Research: A Strategy to Restore Balance*, Washington: National Academy Press, 1990.
7. See National Academy of Sciences, National Academy of Engineering, Institute of Medicine, *Federal Science and Technology Budget Priorities —New Perspectives and Procedures*, Washington, D.C.: National Academy Press, December 1988.
8. See U.S. Congress, Offence of Technology Assessment, "Priority Setting in Science," in *Federally Funded Research: Decisions for a Decade*, (OTA-SET-490), Washington, D.C.: U.S. Government Printing Office, May 1991, pp. 137-167.
9. See Government-University-Industry Research Roundtable, *Federal-State Cooperation in Science and Technology Programs*, February 1992.
10. Source: National Science Foundation, Division of Policy Research and Analysis.
11. These financial data do not include reimbursement for facilities costs, included within indirect cost payments. For further discussion, see Government-University-Industry Research Roundtable *Perspectives on Financing Academic Research Facilities: A Resource for Policy Formulation*, Washington, D.C.: National Academy Press, October 1989.
12. Decisionmaking processes regarding funding responsibilities will need to be developed by the relevant parties involved. For further discussion, see Part III, "Charting a New Course," pgs. 53-58.
13. "Leveraging" as used here refers to the bringing together of resources for the support of research from multiple parties—federal agencies, state government, industry, universities, or philanthropies—to the mutual benefit of all parties. "Cost-sharing" refers to a requirement by research funding agencies that grant awardees or research contractors fund a share of project costs as a condition of receiving the award or contract—in essence, an entry fee.
14. For example, remarks by Walter E. Massey, Director, National Science Foundation, at Director's Seminar, Office of Technology Assessment, September 23, 1991, (unpublished).
15. For a review and analysis of recent literature, see U.S. Congress, Office of Technology Assessment, "Human Resources for the Research Workforce," in *Federally Funded Research: Decisions for a Decade*, (OTA-SET-490), Washington, D.C.: U.S. Government Printing Office, May 1991, pp. 205-230.
16. See, for example: "Indirect Costs: The Gathering Storm," *Science* , 252:636-638, 1991; "Allegations of University Abuses of Overhead System Continue as House Panel Releases a New List of Embarrassing Items," The *Chronicle of Higher Education*, May 15, 1991; "OMB to Cap Overhead Payments for Research," The *Washington Post*, May 16, 1991; and "Overhead Cost Research Dear," *Nature*, 351:255, 1991.
17. Government-University-Industry Research Roundtable, The *Academic Research Enterprise Within the Industrialized Nations: Comparative Perspectives*, Washington, D.C.: National Academy Press, March 1990.
18. See H. Tuckman, S. Coyle, and Y. Bae, *On Time to the Doctorate* , Washington, D.C.: National Academy Press, 1990; and W. G. Bowen, G. Lord, and J.A. Sosa, "Measuring Time to the Doctorate: Reinterpretation of the Evidence," *Proceedings of the National Academy of Sciences, USA*, Vol. 88, pp. 713-171, February 1991.
19. See U.S. General Accounting Office, *Budget Issues: Earmarking in the Federal Government*, Washington, D.C., 1990.

PART THREE

CHARTING A NEW COURSE

CHARTING A NEW COURSE

INTRODUCTION

How are these fateful choices to be made? Here, too, the future will not be like the present. The changing politics of research and the nature of the choices to be made demand new approaches to decisionmaking.

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Wise decisions necessary to achieve a hopeful vision for the future will require a perspective that encompasses a range of essential elements—personnel, programs, infrastructure, and financial support. The interdependence of investigators, their host institutions, and the sponsoring agencies in meeting the requirements of the enterprise must also be considered.

CHANGING POLITICS OF RESEARCH

During the two decades following World War II, the academic research enterprise was composed of relatively few research universities. A few prominent scientists and engineers, representing a small number of fields and institutions, were recognized as national leaders within the U.S. research system. They were generally viewed by the research community as able judges of the system's capabilities, aspirations, and needs. The policy choices confronting these leaders were clear because the research community and the national political leadership had coalesced around a common purpose—to enhance the national security of the United States through an enlarged research capacity.

The U.S. academic research enterprise has expanded nationally and internationally to become the largest such undertaking in the world.

To achieve that purpose, the principal federal role in the academic research enterprise was to provide financial support for the conduct of research and the expanding array of institutions and research fields. The relationship of federal research sponsors and the academic research community evolved in the form of scientific advisory committees and informal interactions. Formal government-university interactions in research, including coordinated or joint planning, were generally viewed, and still are by many, as an inappropriate federal intrusion into the operations of academic institutions and contrary to the autonomy of U.S. universities.

In recent years, however, the research enterprise has changed significantly. These changes have profound implications for decisionmaking. They are:

Diversification. The U.S. academic research enterprise has expanded nationally and internationally to become the largest such undertaking in the world. Including both aspiring and more well-established undergraduate colleges and graduate universities, it boasts well over 200 research institutions. More than 150,000 investigators are active participants in the enterprise. The funding of academic research has be

come more diverse due to increasing levels of support from the states, industry, and the universities themselves.

Competing Purposes. The consensus within the enterprise about a common purpose has dissipated. There are a host of new and exciting research opportunities, but there is no clear identification of or agreement on their relative importance. Today, the objectives of the enterprise are much more diverse. These often competing objectives include not only boosting the nation's basic research capacity, but also strengthening its economic competitiveness, enhancing the environment, and providing the opportunity for all qualified investigators to pursue their ideas to the fullest.

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Interdependence. There is greater interdependence today between academic research institutions and those who fund academic research. Government agencies increasingly rely on university resources and expertise to fulfill their missions. Likewise, universities cannot realize their research and educational aspirations without financial and other support from government agencies.

Changing Composition of the Research Community. Newer members of the research community are bringing different sets of personal expectations and social values to their careers. Within universities, this is causing a reexamination of many traditional features of research careers, including the concept of "mentoring," promotion and tenure policies, and other institutional arrangements. At the national level, the changing composition of the research community', particularly the addition of more women and minorities, means the research enterprise will have to work to create research opportunities for these new entrants and allow them to participate more in decisionmaking activities.

The U.S. research system has reached a size and importance that makes it much more susceptible to outside political intervention and pressure.

Public Visibility. The U.S. research system has reached a size and importance that makes it much more susceptible to outside political intervention and pressure. The research community is in increasing demand to help solve social, economic, environmental, and educational problems at both the national and international levels. Science and technology have taken on more importance as contributors to the economic health of individual regions within the United States, the United States as a whole, and other countries. Regulatory concerns related to the experimental use of animals, radioactive materials, and genetic-engineering have involved the political and legal sectors in certain aspects of the conduct of research. As a result, there is closer public scrutiny of universities, both as stewards of public resources and as guardians of scholarly integrity.

These changes have had the cumulative effect of diffusing the leadership of the enterprise and broadening the array of competing interests and

objectives among the participants. No single group of individuals, no small set of research institutions and no one government agency is in a position to represent the full spectrum of interests and objectives within the U.S. research community, or is sufficiently powerful to make decisions for the whole enterprise.

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SHARED RESPONSIBILITIES

The working group believes the choices facing the enterprise—both near-term decisions and strategic options—will best be made if the broad array of participants in the enterprise—investigators, university administrators, research sponsors, and the political and economic sectors—are involved. It is difficult to imagine making these choices without inter-sectoral participation in decisionmaking and a perspective which encompasses personnel, programs, infrastructure, and financial support.

Near-Term Decisions. Choices about priority-setting and funding responsibilities affect all sectors of the enterprise. Each will want to contribute its perspectives to the choices and listen attentively to the perspectives of others. Such choices can be made only through an ongoing process of deliberations among all affected parties. Each university will have to make choices that best fit its organization, management, and educational programs. Together with larger professional organizations, universities will have to adapt to societal change. University-level decisions will be most effective when faculty and administrators work together.

Strategic Options. Choices about the size and structure of the enterprise will be made not only by those directly involved in the enterprise, but also by participants in the political, economic, and public interest sectors. Indeed, economic and political decisions may be the most important determining factors. For example, expansion could be achieved only with increased public investments in research, which will be governed largely by economic and political decisions. Without support from those two sectors, the tension between unaddressed research opportunities and a limited research budget will only increase. Likewise, while the structure of the enterprise will be determined in part by those who are directly involved in the enterprise, it will be substantially influenced by political decisions.

In sum, both the changing politics of research and the nature of the choices to be made demand a quantum jump in the degree and nature of interactions, communication, and information-sharing by those with a stake in the future of the enterprise.

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NEW APPROACHES TO DECISIONMAKING

There are several mechanisms already in existence that are designed to facilitate communication among universities, the federal government, state governments, and industry. (See box on page 56.) None of these mechanisms currently addresses the full range of issues that the U.S. academic re

search enterprise will face, however, nor do they involve the full range of participants. In addition, none is constituted to carry out joint planning between government agencies and universities, based on the capabilities, constraints, and ambitions of each.

Decisions affecting the U.S. academic research enterprise should be undertaken only through a more deliberate, consensus-building process.

New approaches to decisionmaking at the national level should be considered that incorporate the following characteristics:

Consensus-building. Decisions affecting the U.S. academic research enterprise should be undertaken only through a more deliberate, consensus-building process. This will require a degree of open communication among institutions, agency leaders, and academic faculty that does not now exist. Many expectations and behaviors of those participating in the research enterprise will have to change.

Joint-planning. Well thought out and consistent national policies and priorities will require greater information sharing among universities, government, and industries. Careful monitoring and regular feedback will be required. Research sponsors will have to adopt more consistent funding policies. Universities will have to live up to their part of the bargain, as efficient and honest guardians of the public's money.

Inclusiveness. All key players in academic research—scientists and engineers, university administrators, and government and industry offi

ADVISORY MECHANISMS

Current Mechanisms. Several existing mechanisms facilitate communication among universities, the federal government, state governments and industry. These include agency-specific groups, such as the **National Science Board, the Advisory Committee to the Director of the National Institutes of Health and NIH institute advisory committees**, the **Secretary of Energy Advisory Board**, and the **Defense Science Board**; government-wide groups, such as the **Federal Coordinating Council for Science, Engineering, and Technology** (FCCSET); and non-federal groups, such as the **Government-University-Industry Research Roundtable** (convened by the **National Academy of Sciences, National Academy of Engineering** and the **Institute of Medicine**) and the **Science and Technology Council of the States**.

New Approaches. New approaches to decisionmaking could arise through modifications of these existing advisory mechanisms. For example, the renewal of FCCSET has institutionalized discussions and joint planning among the federal agencies on a broad range of science and technology issues. More broadly, is it possible to further institutionalize government-university-investigator interaction and planning? How can federal agency-specific advisory groups best contribute to such a process? How might the Government-University-Industry Research Roundtable use its convening and analytical roles to better contribute to the decisionmaking needs within the enterprise? How might the current congressional appropriations process for research and technology be better organized so that the needs of the entire U.S. research system are considered?

cials—must take part in the effort. The perspectives of investigators and program managers are vital. They are the ones who understand most fully the emerging scientific frontiers, the requirements for carrying out high-quality research, and the need for excellence in both undergraduate and graduate education. Decisionmaking should also include the perspectives of senior officers of agencies and universities. Their knowledge of institutional needs, capabilities and constraints, resources, operating procedures, and long-term goals is also essential.

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Broad-based Constituencies. Many of the most important influences on the enterprise—political judgments and economic policies, for example—are governed by persons outside of the research community. Thus discussions about the size of the enterprise and the scope of research institutions must involve members of Congress, state governors, and state legislators, among others. In addition to their current decisionmaking roles, these officials must become involved in the previously described consensus-building processes.

Preservation of Local Autonomy. New approaches to decision-making must be sensitive to the states, boards of governors, boards of trustees, and university faculty and administrators, who have ultimate authority for governing and administering the nation's colleges and universities.

A strategy of active interdependence among the various sectors of the research enterprise will entail risks. First, there is the danger of overly centralized decisionmaking. A second danger is that pluralistic approaches may result in incremental or partial outcomes. Third, there is the risk of inaction<.

A strategy of active interdependence among the various sectors of the research enterprise will entail risks. First, there is the danger of overly centralized decisionmaking. Governmental agencies, through their funding and regulatory authority, have greater power to influence the research enterprise than do university faculty and administrations, industry, and the nonprofit sector. A strategy of greater interdependence must avoid intrusive governmental micro-management of the research enterprise. A second danger is that pluralistic approaches may result in incremental or partial outcomes. The nature of the problems facing the enterprise and of the challenges ahead require comprehensive and consistent policies and programs. Third, there is the risk of inaction. Consensus-based decisionmaking processes can be time-consuming and can lack decisiveness. The challenges facing the research enterprise will at times require immediate, bold, or experimental approaches.

LEADERSHIP

Facing up to the difficult choices ahead through active interdependence—while avoiding the risks inherent in pluralistic, consensus-based approaches—requires strong, visionary, and dynamic leadership within each sector of the enterprise. Investigators, through their professional societies and other forums, need to agree on and articulate the research priorities within each scientific and engineering discipline. University leaders need to better articulate the goals, purposes and priorities of their institutions.

Government leaders need to explicitly spell out the government's goals, priorities, and policies for supporting academic research.

If the U.S. academic research enterprise is to enter the 21st century in a position of strength, the increasingly diverse groups and institutions that comprise it must set aside their special interests and join together in common purpose.

Collective leadership is required to define the common purpose of the enterprise as a whole. If the U.S. academic research enterprise is to enter the 21st century in a position of strength, the increasingly diverse groups and institutions that comprise it must set aside their special interests and join together in common purpose. The stakes could not be higher.