THE MISSION OF THE NATIONAL SCIENCE FOUNDATION

HEARING

BEFORE THE

SUBCOMMITTEE ON SCIENCE

OF THE

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

U.S. HOUSE OF REPRESENTATIVES

ONE HUNDRED THIRD CONGRESS

FIRST SESSION

MARCH 3, 1993

[No. 2]

Printed for the use of the Committee on Science, Space, and Technology

U.S. GOVERNMENT PRINTING OFFICE
66-821 CC WASHINGTON : 1993

For sale by the U.S. Government Printing Office
Superintendent of Documents, Congressional Sales Office, Washington, DC 20402
ISBN 0-16-040759-1

66-821 O - 93 - 1

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THE MISSION OF THE NATIONAL SCIENCE FOUNDATION

WEDNESDAY, MARCH 3, 1993

HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
SUBCOMMITTEE ON SCIENCE,
Washington, D.C.

The Subcommittee met, pursuant to call, at 9:40 a.m., in Room 2318, Rayburn House Office Building, Hon. Rick Boucher [Chairman of the Subcommittee] presiding.

Mr. BOUCHER. This morning the Subcommittee on Science continues its inquiry into the future of Federal science policy. Today's hearing, which focuses on the mission of the National Science Foundation, is the first in a series that the Subcommittee will hold during 1993, with the goal of examining the policies which underlie the Federal role in supporting basic and applied research and considering recommendations for changes in those policies.

The fundamental rationale governing Federal science policy was articulated more than 45 years ago in the publication, *Science—the Endless Frontier,* authored by Vannevar Bush. That policy has been refined during the succeeding years of the cold war. The report was the basis for the social contract between government and the research community, and it led in 1950 to the enactment of legislation which created the National Science Foundation.

The assumption that underpinned Federal support for research was that direct benefits to society will arise from funding by the Government of undirected basic research. With some modification, that is still today's policy and today's operating premise.

In 1964, in response to significant changes occurring in society and in the research enterprise in the post-Sputnik era, the Subcommittee on Science, Research, and Development, which was our predecessor subcommittee, initiated a comprehensive review of the operations and functions of the National Science Foundation. The Subcommittee's final report noted that the Foundation was doing well in its core competencies, but that in some respects it had "not kept pace with demands of society, nor adequately oriented itself within the shifting machinery of Government." One reform that was enacted in the wake of that report was a change in the National Science Foundation Act specifically to authorize the Foundation to support applied research efforts, as distinct from the previous mission which was oriented toward basic research.

Today we find ourselves in a period of even more dramatic change. New opportunities and challenges have been created by the end of the cold war, the rise of multilateral economic competition from abroad, and the emergence of global environmental problems.

There are signs of stress in the institutions that perform and support research. Industry's research investment has stagnated. At universities the rapid growth in the number of researchers and institutions, together with the increased costs of conducting research, has outpaced the ability of government and industry to fund worthy research projects, resulting in a rising level of frustration among academic researchers.

Public attitudes toward the research community are also changing as a result of incidents of scientific misconduct, the intense scrutiny of indirect cost recovery by universities, the cold-fusion debacle, and unmet societal needs that are occurring despite a very large public investment in science and technology. The assumption of a direct linear relationship between basic research and societal benefits has now been called into questions.

Taken together, these changes have led the Subcommittee on Science to initiate a broad-based examination of the U.S. research enterprise, including the institutions and Federal policies that underlie Federal support for research. These same factors led the National Science Board, the governing board for the National Science Foundation, to establish a Commission on the Future of the National Science Foundation. The Commission's report commends the NSF for excellence in its core competencies, while recommending changes occur.

Today we have asked Dr. William Danforth, the Co-Chairman of the National Science Board Commission, to highlight the Commission's recommendations. Next, we have asked Dr. James Duderstadt, Chairman of the National Science Board, to describe the Board's plans with respect to the Commission's recommendations. And, finally, we have invited representatives from the President's Council of Advisors for Science and Technology; the Carnegie Commission on Science, Technology, and Government; and the Working Group on the Academic Research Enterprise of the Government-University- Industry Research Roundtable of the National Academy of Sciences to address the implications of their recently published reports for the future mission of the NSF. We've also invited a representative of the Industrial Research Institute to obtain private sector views and perspectives with regard to the NSF's future mission.

The testimony from this hearing will be taken into consideration by the subcommittee as we draft reauthorizing legislation for the National Science Foundation later this year.

I'd like to extend a welcome on behalf of the subcommittee to all of our witnesses and thank them for taking the time to join us here today. We will look forward to each of their comments and recommendations.

Before turning to the first panel of witnesses, I would like to recognize at this time the ranking Republican member of the subcommittee, the gentleman from New York, Mr. Boehlert.

Mr. BOEHLERT. Thank you very much, Mr. Chairman.

Everyone agrees that the United States has the world's premiere basic research enterprise and system of higher education. The National Science Foundation deserves a good deal of credit for these accomplishments. But the performance of the U.S. economy measured against its major competitors demonstrates that educational and research excellence alone are not enough to guarantee continued economic leadership.

Should we conclude then that the Federal Government ought to stop supporting basic research and higher education? No, far from it. I am convinced that continued leadership in basic research and in educating the best scientists and engineers is a necessary, though not sufficient, condition to restoring America's economic competitiveness. Clearly, NSF has a role to play in ensuring that we build on these strengths.

Yet significant questions about the future direction of the Foundation have been dredged up by the competitiveness debate. Among the questions that seem most important are these:

Should the NSF realign the mix of its spending between strategic initiatives and principal investigator, curiosity-driven research proposals?

Do strategic initiatives, as well as major instrument programs like LIGO, threaten to become entrenched in NSF's budget to the detriment of flexibility and funding for principal investigators?

What role should NSF play in addressing our declining manufacturing expertise?

What steps can NSF take to increase the emphasis on quality teaching in our universities and colleges?

Can we establish measures by which we can assess the performance of the Foundation?

What role should the Foundation and the National Science Board play in shaping a national vision on science and technology policy?

Are NSF's initiatives on K through 12 science education on target?

I've got a lot of questions, Mr. Chairman, and the witnesses we'll have here today are experts and they'll give us some direction in terms of answers.

Let me say here and now—let me repeat something that I've said many times, but I never miss an opportunity in this town to say this—if we're going to be serious about moving our economy forward, if we're going to be serious about recapturing our manufacturing base, we've got to start being realistic in establishing priorities, priorities in the area of science. Now I, for one, am not at all reluctant to take great pride in the fact that I'm trying to realign our priorities.

I think, for example, that it's absolutely obscene for this Government and this country to be spending the amount of money we're spending on the Superconducting Supercollider when all those worthy applications for principal investigators are going unfunded at NSF and NIH. Where are our priorities? We've given more money than ever before to NSF and NIH, and to NIST, too, and we should give even more, but we've got to get sensible about our priorities.

So I have already informed the Director of the Office of Management and Budget, a former colleague of mine, Mr. Panetta, that I've accepted the President's challenge and I'm going to be issue-specific. We're going to do away with the funding for the SSC. We're going to redirect those dollars to important research, to some of the activities that are under the jurisdiction of the National

Science Foundation, because of all the agencies of the Federal Government, this is probably one of the best-kept secrets that does so much so well for so many.

Mr. Chairman, it's a pleasure to open this hearing today and it's a pleasure to work with you because I know we're on the same wave length with respect to NSF, and I'm going to do my best to get you on the same wave length with the SSC. Thank you.

[Laughter.]

Mr. BOUCHER. Thank you very much, Mr. Boehlert, for those thoughtful comments, and we'll reserve debate on the SSC for a future date, unless the gentlelady from Texas would like to participate in that now.

Mr. BOEHLERT. Mr. Chairman, I do wish to note that this subcommittee does have jurisdiction over the SSC now, as you well know.

Mr. BOUCHER. There is no doubt about that.

[Laughter.]

The gentlewoman from Texas, Ms. Johnson.

Ms. E.B. JOHNSON OF TEXAS. Thank you very much, Mr. Chairman. I'm not so sure I'm happy to be here this morning or not. I left another meeting to come and I came in at the wrong time to listen about the attack on the SSC.

I do feel very strongly, Mr. Chairman, that this is an important committee and the issues of which we discuss really will show our vision for the future or our failure to meet the challenges for the future.

And I look forward to listening to the witnesses and working with this committee and trying to outnumber Mr. Boehlert of New York.

[The prepared statement of Mr. Barcia follows:]

Statement

Hon. James A. Barcia

Committee on Science, Space and Technology
Subcommittee on Science

I thank the chair for calling this hearing. The vitality of this nation's premier science and technology agency is of great importance. At a time when the centrality of military power is diminishing, and the importance of economic and intellectual power is becoming ever greater, a review of the National Science Foundation's (NSF) activities is most appropriate.

The contribution's that have come from this agency's activities are immense. And hopefully with a sharpening of the policies that drive the agency I am certain this will continue. The results of the National Science Board's Commission on the Future of the NSF provides this committee, and the Congress, a well thought out and balanced platform from which to begin refining NSF's mission.

The need to direct scarce national resources towards science and technology issues is evident. The vibrant activity in the science and technology community, and its contribution not only to our economic well being, but our fundamental understand of the world we live in, is a national asset in itself.

This vibrancy is well illustrated in the many bodies that have spent time in formulating recommendations on our science and technology goals. Just one example is the Carnegie Commission on Science, Technology and Government which has, as I am sure is well known, published a series of monographs on many aspects in the science and technology policy arena.

Again I thank the chair, and I look forward to hearing the testimony of the witnesses called here today.

Mr. BOUCHER. Thank you very much, Ms. Johnson.

We welcome now our first panel of witnesses: Dr. William H. Danforth, the Co-Chair of the National Science Board Commission, on the future of the National Science Foundation, and Chancellor of Washington University in St. Louis, Missouri; and Dr. James Duderstadt, Chairman of the National Science Board and president of the University of Michigan at Ann Arbor.

Without objection, your prepared statements will be made a part of the record, and we would welcome your oral summary.

And, Dr. Danforth, we'll be pleased to begin with you.

STATEMENT OF DR. WILLIAM H. DANFORTH, CO-CHAIR, NATIONAL SCIENCE BOARD COMMISSION ON THE FUTURE OF THE NATIONAL SCIENCE FOUNDATION, AND CHANCELLOR, WASHINGTON UNIVERSITY, ST. LOUIS, MISSOURI; ACCOMPANIED BY DR. JAMES J. DUDERSTADT, CHAIRMAN, NATIONAL SCIENCE BOARD, AND PRESIDENT, UNIVERSITY OF MICHIGAN, ANN ARBOR, MICHIGAN

Dr. DANFORTH. Mr. Chairman, thank you very much. I'm William Danforth, Chancellor of Washington University—

Mr. BOUCHER. And let me ask if you would turn your microphone on, we'll hear you a bit better. Thank you.

Dr. DANFORTH. Thank you, Mr. Chairman. I'm William Danforth, Chancellor of Washington University in St. Louis. It's a privilege to speak here before this panel today, and it was also a privilege to be co-Chair of the four-month study of the National Science Foundation conducted with a talented group of business people and academics, and in the next few minutes I shall try to hit a few high points of our report, offer some personal conclusions, and respond to the questions raised in your letter.

First, it's important to put the National Science Foundation in perspective. The NSF spends about $2 billion annually on research. That is about 3 percent of the total Federal research and development expenditures of $76 billion. It's about 1 percent of the national R&D expenditures. The NSF spends $487 million on science and math education. The Department of Education spend $14 billion on all of education. These relatively small expenditures of the Foundation might be thought of as like a vitamin, a small ingredient essential to the health of American science and engineering.

Now the National Science Foundation has a special responsibility, one might say a special niche in the total Federal R&D program. The niche has been scientific research and research fundamental to the engineering processes. How that niche is exploited is important, too. The monies have been spent largely in the Nation's universities with the goal of tapping into the brain power of the country's scientific minds, asking for their ideas and proposals, and then funding the very best. In this way, the Foundation is dependent on the creativity of a large number of minds rather than on the ideas of the few, however wise those few might be.

Moreover, it supports the infrastructure and keeps alive a science and engineering establishment ready for problems and opportunities as they come along. Today the NSF funds most of the underlying science for chemistry, geosciences, mathematics, physics, engineering, as well as important areas of biology, computer science, and the social behavioral and economics sciences, where it has sparked innovation.

It is for practical purposes the sole funder of ecology, evolution, and systematic biology. These are areas that are so important to dealing with the environmental problems.

I could make similar remarks about the educational programs of the Foundation. Their special niche is to improve math and science education. The programs have been and must continue to be coordinated with the Department of Education in order to continue to get the most leverage from the relatively small amount of dollars spent.

Our Commission believes that the NSF just can't be thought about in a vacuum. Rather, it's important to understand how the agency fits into the total Federal effort in science and technology. We suggested that the National Science Board recommend a stronger national science policy covering science and technology that goes beyond the NSF. Presumably, the President's Science Advisor, working with Congress, would be the individual to take the lead, but of course the NSF and the NSB would participate and play an important role in the development of such a policy. The NSF should support both the needs of the Nation and the Foundation's special role in a coordinated, overall governmental program.

Some have worried that, whatever the quality of the NSF-supported research, American corporations are not recognizing and using the ideas coming from it. We do not agree. The report reads, "Failures in the marketplace have not been the result of slow transfer of academic science to industry. In fact, American firms have been the first to commercialize virtually all innovative products, but have lost market share to competitors with shorter product cycles, lower costs, and superior quality. All manner of other more important factors, including the stewardship by American business, far outweigh whatever could be traced to the technology itself or the technologists."

Now by no stretch of the imagination do we mean that the transfer of ideas back and forth between universities and industrial scientists cannot be improved. On the contrary, we suggest several ways of doing so; for example:

More scientists from user communities, especially from business, might sit on the NSB, therefore, playing a greater role in setting policies and evaluating results.

Exchange of people between industry and academia could be stepped up.

Diffusion and dissemination of knowledge and skills could be strengthened.

The development of joint science, engineering, and management programs should be encouraged.

The world is changing; the NSF must adapt and change. Its priorities must evolve along with the Nation's needs and with science itself. Our committee reaffirmed the basic mission of the NSF. We believe that the missions in the NSF spelled out in the enabling legislation as amended are broad enough to allow for these adjustments. We believe, further, that the traditional focus and the large goals of NSF are as important as ever and are likely to become even more important as American industry and corporations are positioning themselves to use science ever more effectively. No other agency duplicates what the Foundation does.

Strategy and balance between programs should be reviewed regularly and appropriate adjustments made, as in the past. We did not spell out how to do so, but I would imagine the NSF would make reports and offer recommendations to the National Science Board, which might modify them, and eventually these reports and recommendations would be made to the White House and to Congress.

Evaluations can best be started by the administration and by the National Science Board. We recommend the development of common-sense metrics. To do so is a management responsibility. People who know the operation intimately can set up the most effective measurements.

I can give you a few "for instances," not to recommend them, but for illustrative purposes only. One could look at the efficiency of the operation itself and measure such things as turnaround time on grant applications, costs of evaluating applications, and so on. On the other hand, one can measure the quality of the output, such as the number of times research work performed with Foundation funds is cited by other researchers, and so on. Measuring the long-term success, of course, is difficult, and one of the challenges of this committee and the success may—real measurements may take years.

We concluded that it would be difficult to follow our recommendations without an increase in resources, for the budget of the NSF is already inadequate even to support its present responsibilities. We believe that a careful look at the total Federal R&D budget and the total needs of the Nation would bear us out. The value of Federal support for R&D could be multiplied, we believe, without increasing Federal expenditures by reallocation of funds with an eye to making the essential linkages and feedback between education, discovery, development, application, competitiveness, and quality of life.

In sum, we affirm the basic mission. We call for not radical change, but rather steady improvement. We believe that the entire national R&D system could function more effectively so as to lower the cost of improving the quality of life, add value throughout society, and create true wealth and opportunity for the country.

Thank you.

[The prepared statement of Dr. Danforth follows:]

HEARING ON

THE MISSION OF THE NATIONAL SCIENCE FOUNDATION

MARCH 3, 1993

TESTIMONY OF

WILLIAM H. DANFORTH
CHANCELLOR, WASHINGTON UNIVERSITY

BEFORE THE
SUBCOMMITTEE ON SCIENCE
COMMITTEE ON SCIENCE, SPACE AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES

I am William H. Danforth, Chancellor of Washington University in St. Louis.

It is a privilege to speak here in this forum about the four month study of the National Science Foundation (NSF) conducted with a talented group of business people and academics. In the next five minutes I shall hit a few high points of our report, A Foundation for the 21st Century: A Progressive Framework for the National Science Foundation. I shall offer some personal conclusions and try to respond to questions raised.

First, it is important to put the NSF in perspective. The NSF spends about $2.0 billion annually on research; that is about three percent of the total federal research and development expenditures of $76 billion and about 1 percent of the national R&D expenditures. The NSF spends $487 million on science and math education. The Department of Education spends $14 billion on all education. These relatively small expenditures of the NSF might be thought of as a vitamin, a small ingredient essential to the health of American science and engineering.

The NSF has a special responsibility, one might say a special niche, in the total federal R&D program. This niche has been scientific research and research fundamental to the engineering processes. How that niche is exploited is important also. The monies have been spent largely in the nation's universities with the goal of tapping into the brain power of the country's scientific minds, asking for their ideas and proposals and then funding the very best. In this way the NSF has depended on the creativity of a large number rather than on the ideas of the few, however wise the few might be. Moreover, it supports the infrastructure and keeps alive a science and engineering establishment ready for problems and opportunities as they come along. Today the NSF funds most of the underlying science for chemistry, geosciences, mathematics, physics and engineering, as well as areas of biology, computer science and the social, behavioral and economic sciences where it has sparked innovation. It is for practical purposes the sole funder of the fields of ecology, evolution and systemic biology which are so important to understanding the environment.

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Our Commission believes that the NSF cannot be thought about in a vacuum. Rather, it is important to understand how the agency fits into the total federal effort in science and technology. We suggested that the National Science Board (NSB) recommend a stronger national policy covering science and technology; presumably the President's Science Advisor, working with Congress, would be the individual to take the lead, but, of course, the NSF and the NSB would participate and play an important role in the development of such a policy. The NSF should support both the needs of the nation and the foundation's special role in a coordinated program.

Some have worried that whatever the quality of the NSF supported research American corporations are not recognizing and using the ideas coming from it. We do not agree. The report reads:

> Failures in the marketplace have not been the result of slow transfer of academic science to industry. In fact, American firms have been the first to commercialize virtually all innovative products, but have lost market share to competitors with shorter product cycles, lower costs, and superior quality. All manner of other more prominent factors, including the stewardship by American business, far outweigh whatever could be

> traced to the technology itself or the technologists. (Report, p.3)

By no stretch of the imagination do we mean that the transfer of ideas back and forth between universities and industrial scientists cannot be improved. On the contrary, we suggest several ways to do so, for example:

- More scientists from user communities, especially from business, should sit on the NSB, thereby playing a greater role in setting policies and in evaluating results.

- Exchange of people between industry and academia should be stepped up.

- Diffusion and dissemination of knowledge and skills should be strengthened.

- The development of joint science, engineering and management programs should be encouraged.

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We concluded that it would be difficult to follow our recommendations without an increase in resources, for the budget of the NSF is already inadequate even to support its present responsibilities. We believed that a careful look at the total federal R&D budget and the total needs of the nation would bear us out. The value of federal support for R&D could be multiplied by reallocation of funds with an eye to making the essential linkages and feedback between education - discovery - development - application - competitiveness - quality of life.

In sum, we affirm the basic mission. We call for not radical change, but rather steady improvement. We believed that the entire national R&D system could function more effectively so as to lower the cost of improving the quality of life, add value throughout our society and create true wealth and opportunity for the country.

William H. Danforth, M.D.
Chancellor
Washington University
St. Louis, Missouri 63130

Dr. William H. Danforth became Washington University's thirteenth Chancellor on July 1, 1971.

Born in St. Louis, Missouri, on April 10, 1926, he received his B.A. from Princeton University and his M.D. from Harvard Medical School in 1951. After completing his internship in medicine at Barnes Hospital, St. Louis, Missouri, he served in the United States Navy from 1952-54. He returned to St. Louis to continue his medical training at Barnes Hospital and at St. Louis Children's Hospital.

Dr. Danforth joined the Washington University Medical School faculty in 1957. In 1967, he was appointed professor of internal medicine, which is his present faculty rank at the University. From 1965-71, Dr. Danforth served as Vice Chancellor for Medical Affairs and as president of the Washington University Medical Center. He is a member of the National Academy of Sciences' Institute of Medicine and served on the Council 1977-79.

Dr. Danforth is chairman of the board of trustees of the Danforth Foundation and is a trustee of the American Youth Foundation. He is chairman of the board of governors of the St. Louis Christmas Carols Association. He serves on the boards of directors of Ralston Purina Company and McDonnell Douglas Corporation, both headquartered in St. Louis, Missouri.

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Mr. BOUCHER. Thank you, Dr. Danforth.
Dr. Duderstadt?

Dr. DUDERSTADT. Thank you, Mr. Chairman. I'm Jim Duderstadt, Chairman of the National Science Board and president of the University of Michigan. And I'd like, first, to thank you for the opportunity to testify on the mission of the National Science Foundation, but beyond that, to thank you and Chairman Brown for taking on the difficult task of examining the implications of the new and possibly even more comprehensive vision of national science policy in our Nation's future.

As you are aware, the National Science Board itself serves dual roles, both as the Board of Directors of the National Science Foundation and as well as the body with the responsibility for the development of broader science policy. It was in this latter role that the Director of the National Science Foundation, Walter Massey, approached us with a request that we examine the impact of the great changes of our times—political, social, and economic—in a domestic and, indeed, international context, the impact of those changes on scientific research and education and on the future of the National Science Foundation. We agreed that the most effective approach to do this was to establish an external commission, a commission on the future of the National Science Foundation, and we asked Chancellor Danforth and Robert Calvin of Motorola to cochair this effort.

This Commission was charged with providing an independent assessment of the effects of a rapidly changing world on the NSF's mission and recommending possible changes in the activities, the mission, the function of both the NSF and the National Science Board itself. Dr. Danforth has spoken directly to the report, "A Foundation for the 21st Century," but I would like to take this opportunity to thank him and his colleagues once again for a truly magnificent effort under rather considerable time pressures and other constraints to respond to the charge and acknowledge that they have provided a report that will serve as an important framework for developing a longer-range strategy for the Foundation.

As Dr. Danforth mentioned, the Commission strongly reaffirmed the fundamental importance of continuing the NSF's basic mission of supporting first-rate research, identified and defined by the best researchers in the academic research community; that is, stressing curiosity-driven, peer-reviewed activities. But at the same time, they also underscored the importance of supporting key strategy areas in response both to scientific opportunities and the need to meet national goals.

The Commission identified a series of issues and recommendations that deserve and will receive further deliberation by the Board and, indeed, the broader scientific community: how we can better support evolving research fields, taking into account the increasing interdisciplinary nature of research and teaching, the issues of grant size, of improving science education, of knowledge diffusion, the increasing dependencies among the many stages in technology development, the very critical facilities infrastructure needs of modern scientific research.

And, yet, as Dr. Danforth has also mentioned, the Commission also acknowledged that today we find the NSF budget inadequate to support even its present array of responsibilities, much less to respond to the challenges, the opportunities, the responsibilities before it. From this perspective, the Board understands and agrees with the strong recommendation of the Commission that the present and proposed responsibilities of the Foundation and its consequent resource needs must be examined within the context of a newly conceived Federal science and technology policy which is better capable of responding to national needs. The Commission also urged quite strongly in several places in the report that the National Science Board step up to its statutory responsibility to be a full participant in the development of this broader Federal policy.

The issues, the recommendations raised by the report will serve as the focus for an intensive series of discussions that will be held by the Board over the next year. We formed a special task force, chaired by Dr. Frank Rhodes, a member of the Commission, a member of the National Science Board, and president of Cornell University, to guide the Board through this series of discussions, and we intend to use the Commission's work to provide a framework for broader dialog as well with the scientific community and with public leaders during this period.

The particular issues raised in the letter of invitation to these hearings have been addressed in my written testimony, and in these short opening remarks I will not dwell on them, but I would like to conclude by commending you and your colleagues once again for undertaking this assessment of the health of the American scientific research enterprise.

As we enter an age in which knowledge itself has become the key to national security, prosperity, social well-being, the role played by universities to the conduct of scientific and engineering research and education, and the future key Federal partners such as the National Science Foundation in supporting these activities have become absolutely critical to our Nation's welfare.

Thank you very much.

[The prepared statement of Dr. Duderstadt follows:]

Testimony of

James J. Duderstadt

Chairman, National Science Board

Before the House Subcommittee on Science of the

House Science, Space, and Technology Committee

March 3, 1993

Mr. Chairman, thank you for the opportunity to testify this morning on the mission of the National Science Foundation. It is an honor to be a part of this hearing, the first in a series on the health of research. I commend both you and Chairman Brown for taking on the difficult task of examining the implications of a new and possibly more comprehensive vision of national science policy.

The National Science Board is responsible for articulating positions on matters of national science policy as well as providing guidance in the ongoing development of science policy as it is expressed through the various programs at the National Science Foundation. However, in recent years the pace of change in science, to say nothing of the pace of change in domestic and world affairs, has required the Board to examine science policy against a background unlike anything in our past experience.

These rapid changes have made it desirable for us to take a fresh look at the rationale, the planning process, and the implicit assumptions in Federal support of mathematics, science, engineering research and education.

Walter Massey, Director of the National Science Foundation, acknowledged the need to confront a changing world when he requested that the National Science Board establish a commission to examine the future of NSF. The role of the commission was to provide an independent assessment of the effects of a rapidly changing world on NSF's mission.

The establishment of the Commission on the Future of the National Science Foundation and the coinciding request for comments from interested parties generated hundreds of responses from throughout the academic and industrial research community. Dr. Danforth will speak more directly to the work of the Commission, but I should note that the Commission's report has been received by the Board and is viewed as a very important source of information and analysis.

At its February 12 meeting, the Board decided that, consistent with the recommendations of the Commission, we will further examine our own role and contributions in setting national science policy and directions. The Board also noted the importance of continuing the constructive dialogue established with the science and engineering communities as part of the Commission activities. Specific strategic planning issues identified by the Commission, such as the nature of NSF partnerships with other entities, have been designated for full discussion at future Board meetings.

In addition, language in the Commission Report on grant size and the importance of strategic research was referenced by Walter Massey to support the President's request for supplemental funding for NSF in FY 1993. So the Commission's work is already serving a very useful function.

The first issue that I want to address is whether we can conclude from these experiences and analyses that the mission of NSF should change. From one perspective, NSF's mission has changed every year since its inception. NSF has responded by providing increased resources in education, by expanding into engineering research, by creating mechanisms to engage in partnerships with other agencies, by developing ways to encourage the reform of entire state math and science educational systems, and by incorporating new areas of research -- and new models for conducting research -- into its portfolio.

From a broader perspective, NSF's mission has remained consistent and true to its initial charge -- to support science and engineering research and education in order to advance national health, prosperity, and welfare. A large proportion of this research is instigated at the level of the individual investigator based only on considerations of his or her best scientific intuition about a problem. Other research may be guided by a strategy that looks ahead to the possible utility of the research. At the extremes, these are fairly easy to distinguish, but in the vast majority of cases the classification of research into one category or another is arbitrary.

The Commission recommended an appropriate balance between curiosity-driven research and strategic research. It is difficult to provide an exact metric for this balance if one takes the view that this distinction is somewhat subjective. Given NSF's current funding level, the mix is approximately correct. NSF's primary obligation is to maintain the excellence and health of curiosity-driven research. NSF's ability to respond to important new challenges and opportunities that contribute to the national interest depends on an adequate resource base. Under any circumstance, it is important that we seek mechanisms that will shorten the distance between new knowledge and its potential utility.

Right now NSF supports excellent research in a number of areas relevant to national needs, such as education, global climate change, advanced materials, biotechnology, high performance computing and communication, and advanced manufacturing.

Some of these programs are also part of an effort to provide a more coherent research policy within the government, and as such represent one area where NSF has developed effective working partnerships. Over the years NSF has been at the forefront of establishing long-standing partnerships with consortiums of academic institutions, with small businesses, the states, industrial concerns, and various combinations of these entities. The fact that NSF has had successful experiences in many varied partnership arrangements suggests an increased role for future partnerships when opportunities arise.

Concern has been expressed that future partnerships might entangle NSF in industrial research activities that are not driven by science. Such fears are unfounded. In areas where NSF can advance science and engineering by bringing together resources and talent in unique settings, it has an obligation to do so. Federally funded research can and should have identifiable economic and social benefits, but first and foremost it should represent excellence in science and engineering.

Given this focus on quality, the committee's concern about how we evaluate the overall quality of NSF's research is well taken. Programs at NSF are continually initiated, evaluated, re-focused, de-emphasized or terminated if need be. Every directorate is evaluated by a Committee of Visitors at least once every three years. These evaluations are based on the informed opinions of researchers from both academia and industry. In addition, the

National Science Board, in its oversight of NSF, provides ongoing evaluations of it activities.

Before concluding my testimony, I would like to address the role of the National Science Board in developing a coherent national science and technology policy. The NSB has, in the years since it was established, assumed responsibility for health of the infrastructure of the nation's science and engineering research and education activities. As such, it has played a critical role in focusing attention on issues of math, science, and engineering education at all levels, the health of the academic research enterprise, national research facilities, and the link between science and engineering research and the nation's well-being.

This National Science Board is now looking at what its role should be in the future. As a more coherent national science and technology policy is debated, I think it is important that the NSB should continue as the focal point for deliberation on how any policy will affect and be affected by our science and engineering infrastructure.

Mr. Chairman, this concludes my testimony and I thank you for the opportunity to present my views to the subcommittee today.

A Foundation for the 21st Century:

A Progressive Framework for the National Science Foundation

Report of the National Science Board Commission on the Future of the National Science Foundation

November 20, 1992

Letter of Transmittal

Dr. James J. Duderstadt
Chairman, National Science Board

Dear Dr. Duderstadt:

On behalf of the Commission on the Future of the National Science Foundation, we are pleased to present the attached report.

We call the attention of the Board to the extraordinary outpouring of very thoughtful letters from individual scientists and from institutions large and small elicited by its charge to this Commission. Many of these letters are the result of serious drafting by very well informed people. The Board should not only study this material but should be mindful of the opportunities in the future to use this method for an extended dialogue on matters of great moment to the nation.

We are also grateful to those who have spoken with us formally and informally. The report could not have been completed in a timely manner without the support of you, Dr. Walter E. Massey, Dr. Charles Brownstein, and many others on the staff of the Foundation.

We hope that our recommendations may lead to a better understanding of the role of science and engineering in meeting national goals and a better linking of scientific results with those goals.

We are honored to have been given this responsibility and to have worked with the distinguished members of the Commission.

William H. Danforth
Washington University

Robert Galvin
Motorola, Inc.

Co-chairpersons

November 20, 1992

NATIONAL SCIENCE BOARD COMMISSION ON THE FUTURE OF THE NATIONAL SCIENCE FOUNDATION

WILLIAM H. DANFORTH
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Executive Secretary, Charles N. Brownstein
National Science Foundation

Preface

James J. Duderstadt
Chairman, National Science Board

The establishment of an external commission by the National Science Board is a remarkable event. Over the past 40 years the Board has established external commissions on only a handful of occasions when circumstances suggested the need for an impartial and expert consideration of significant issues of national science policy.

In the context of long range planning discussions with the National Science Board, the Director of the National Science Foundation, Walter E. Massey, explored with the Board the challenges facing NSF in the future and the Foundation's appropriate responses. Accordingly, he recommended and the Board established the Commission on the Future of the National Science Foundation.

As the Commission notes at the outset of its report, the transformation of the political, economic, and social context occurring both domestically and abroad is changing how we as a society view and support science and engineering research. The Commission stresses the fundamental importance of continuing the National Science Foundation's basic mission of supporting first-rate research, identified and defined by the best researchers within the academic research community. At the same time the Commission also underscores the importance of supporting key strategic research areas in response to scientific opportunities to meet national goals.

The report notes that the challenges the National Science Foundation faces go to the core of our assumptions about the role of science in our society. In the context of enhanced public confidence in and support of science and engineering research the Foundation must better position itself to respond to strategic research opportunities. Strong linkages between research and education will be critical to this endeavor, as will more effective partnerships between the academic research community and other sectors of our society such as industry and government.

Throughout the report, the commission identifies challenging issues that will require NSF attention. These include evolving research fields, interdisciplinary opportunities, increasing dependencies among stages in technology development, grant size, student support, improved science education, knowledge diffusion and facility needs. Yet the Commission also acknowledges that the NSF budget is inadequate to support even its present responsibilities and programs and that the National Science Foundation will find it difficult to respond to these new challenges without an increase in resources.

From this perspective, the Commission strongly recommends that the NSF's responsibilities and opportunities—both present and proposed—and its budgetary needs be examined within the context of a newly conceived Federal R&D budget capable of responding to national needs. To this end, the Commission urges that its recommendations be considered by the National Science Board in the context of the Board's own responsibility to develop and carry out national policy for science and engineering research and education more broadly.

The Commission report affirms the importance of the NSF's historical mission, provides an excellent starting point for assessing the new environment for research and education, and offers recommendations for meeting the needs imposed by these changes. The wisdom contained in the pages that follow will inform discussions within the Board and the broader scientific community on issues important to both the National Science Foundation and to the nation.

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Background

THE UNITED STATES is preeminent in science thanks to public support for patient and judicious investment, private as well as public, since World War II. As a result of the government's reliance on universities for much of the nation's basic research, American graduate education in the sciences and engineering leads the world.

The National Science Board (NSB) and the Director of the National Science Foundation (NSF), in a spirit of self examination, have asked this Commission to stimulate thinking on long range strategies for the Foundation.

The task is important:

- despite having only about three percent of the total federal R&D budget, the NSF has for over 40 years played an essential role in the scientific primacy of the United States;

- the NSF serves as a major source of new scientific and engineering ideas and skilled people underpinning broad sectors of our economy and our society.

The NSF serves as a major source of new scientific and engineering ideas and skilled people underpinning broad sectors of our economy and our society.

And timely:

- expectations for benefits from scientific and engineering research, including economic growth, are growing and changing;

- the U.S. is competing in an expanding global market place;

- there is realization that scientific leadership does not translate automatically into economic success for American industry;

- corporate research is becoming more sharply focussed on market-related issues, with fewer companies supporting long term research;

- there are calls for greater accountability.

Key to the success of the National Science Foundation in building American science has been:

- its broad mandate to strengthen American science and engineering;
- a partnership of trust built with America's scientists, engineers, and academic institutions;
- investigator initiated proposals and selection of the best of these proposals on the basis of merit;
- strong educational programs;
- the flexibility to pursue new ideas.

Today, America's hopes for benefits from science focus additionally on:

- greater economic success;
- better health and less expensive health care;
- protection of the environment;
- continuing military security in a changing world;
- other improvements in the quality of life, including communications, transportation, housing, efficient use of resources, and better education of young people.

With shifts in emphasis from defense to civilian concerns, the private sector is an increasingly important consumer of new scientific knowledge. Changes in American businesses and universities hold promise of a more receptive adoption and practical application of the knowledge born of research and advanced education. These include:

- more progressive quality processes, and operations standards and systems;

- a realization that longer term versus shorter term thinking and planning is necessary;

- an increase in shared funding of research and engineering by industry and state and local governments;

- academic scientists working more closely with industry.

Changes in American businesses and universities bold promise of a more receptive adoption and practical application of the knowledge born of research and advanced education.

An important national priority is to improve the relative industrial strength of the United States. The National Science Foundation can make contributions to economic success, but developing a plan to do so must begin with an understanding of the system and of the reasons for failure of some industries in world markets.

Failures in the market place have not been the result of slow transfer of academic science to industry. In fact, American firms have been the first to commercialize virtually all innovative products, but have lost market share to competitors with shorter product cycles, lower costs, and superior quality. All manner of other more prominent factors, including the stewardship by American business, far outweigh whatever could be traced to the technology itself or the technologists.

Success requires: an enlightened federal science and technology policy that touches all relevant agencies, a determination by industry to reach out for talent and knowledge, and the development of appropriate links. The universities and the NSF should complement rather than replace the roles of those engaged in technology development.

Redirecting the NSF's activities from research and education would have little or no effect on the U.S. competitive position in the near term, but would severely restrict prospects for the long term. Research and education activities offer ample opportunity to increase the potential contribution of scientists and engineers to society.

We therefore commend to the National Science Board the following recommendations.

Findings and Recommendations

CHANGE IS PART of the national agenda. NSF, and the colleges and universities it supports, are in a position to help create a new vision of and value from the role of science and engineering for society.

To realize these benefits more fully, the Commission commends to the National Science Board and the broader scientific community these:

General Recommendations

1. The United States should have a stronger and more coherent policy wherein science and engineering can contribute more fully to America's strength.

   The Board is encouraged to work with the President, his Science Advisor, and the Federal Coordinating Council on Science, Engineering, and Technology (FCCSET) to assess the health of science and engineering broadly and to generate a stronger policy into which the NSF mission fits. This thesis is amplified in the conclusion of the report.

2. Society's voice is welcome and needed.

   Society's support for the NSF and for university research is based on the confident expectation that the generation of new knowledge and the education of a skilled workforce are necessary (though not sufficient) investments to achieve our national goals of a high quality of life in a productive and growing economy. In accepting society's support, the scientific community naturally assumes an obligation to be both responsive to national needs voiced by society as well as the intellectual priorities solely initiated by the scientist or engineer.

Concern over technology application and competitiveness sometimes conjures a choice that budgeting is decided on either the criteria to please the scientists or to serve the public need. In reality these criteria and interests are congruent.

The history of science and its uses suggests that the NSF should have two goals in the allocation of its resources. One is to support first-rate research at many points on the frontiers of knowledge, identified and defined by the best researchers. The second goal is a balanced allocation of resources in strategic research areas in response to scientific opportunities to meet national goals.

It is in the national interest to pursue both goals with vigor and in a balanced way. The allocation of resources should be reviewed regularly with these two goals in mind. Positive responses to both will enhance the standing of science.

NSF should have two goals.... One is to support first-rate research at many points on the frontiers of knowledge, identified and defined by the best researchers. The second goal is a balanced allocation of resources in strategic research areas....

3. The Commission strongly supports the initiation of proposals by investigators and selection of those to be funded by merit review carried out by experts. This method has proved to be the best way of tapping into the creativity of research scientists and engineers. Periodic examination of how to improve the functioning of the system is in order. The system, of course, must assure the selection of work of the highest quality and promise.

4. The NSB, the NSF, and the science and engineering community must better come to grips with the reality that many fields not covered by traditional disciplines offer challenges for new knowledge and opportunities for creative, investigative research worthy of the most gifted scholar. These fields should be valid candidates for support and may both yield key knowledge and enable timely response to national goals.

5. Since the private sector plays the major role in the translation of knowledge into new products and services, and since the speed and efficiency of this process is an important factor in a productive and growing economy, it is appropriate that the NSB involve the private sector more fully than heretofore in the decisions which affect the classes of

research allocation as well as some evaluation of the effectiveness of the expenditures. It is more than incidentally significant that scientific advances are as likely to be driven by advances in technology as the reverse, and the interplay between parties who are conversant in both fields holds promise of synergy.

Research Recommendations

Nature knows nothing about disciplinary boundaries.

1. The Board and Foundation's key role in the support of research in science and engineering should be strongly reaffirmed.

2. The NSB and the NSF should encourage interdisciplinary work and cooperation among sectors. Nature knows nothing about disciplinary boundaries.

3. There is a convergence between science and technology arising from technology today having a stronger basis in theory and data, which creates increased demand for research at every stage of the innovation process. Goals for science are, for the most part, necessarily long-term. However, new knowledge from fundamental research is important early-on, to the technical community, as a guide for anticipating future progress in technology and in the selection of strategies for future developments.

   Commercial technology is to a significant degree the result of the work of the NSF, although it is not what the NSF does. NSF and its research and education programs do have much to do with making possible new technologies.

4. It is urged that the size of NSF grants be examined. Many believe that on average, NSF individual research grants are too small. Examination of separate fields and wide consultation within the community would help in understanding the issues. We favor research grants sufficient to do the work for which the grant is awarded.

5. The management of NSF should from time to time review the make up and combinations of Directorates to maintain the most effective focus and management of the selection process, taking into account the evaluation of research, the desirability of interdisciplinary research, the needs of different types of research and efficiency of operation.

6. The diffusion and dissemination of the knowledge and skills derivable from scientific and engineering discoveries are important. Although complex, the system is working better than many presume. It works particularly well when university trained researchers and professionals move from position to position in academia or in industry.

   Dissemination is improvable by:

   a) further encouragement of cross-disciplinary collaboration;

   b) facilitating exchanges of people between universities, industry, and government;

   c) utilizing the collective advice of the scientists and engineers in industry, universities, and government agencies;

   d) support of research with active industrial participation;

   e) more effective circulation of scientific discoveries through publications, conferences and networking;

   f) continuing funding for the maintenance of and access to large scale data bases;

   g) development of information infrastructure, such as NSFNET, to facilitate communications, research collaboration, and remote access to shared resources and facilities.

7. The Foundation should more aggressively lead in communicating the "case" for science and engineering, which deserve a high priority in the mind of public officials and citizens alike.

   There is a widespread lack of appreciation of the complex interconnected processes by which new knowledge eventually leads to societal benefits. This exists in the university and scientific communities as well as in the halls of government. The NSF should take the lead in interpreting this process to all of its publics.

8. The NSF should both set an example and work with others in fostering international cooperation and agreements for the most effective exchange of research results and for research collaboration. To do so is beneficial to all parties, as important discoveries can be made anywhere.

Undergraduate education is enriched by faculty participating in research.

9. Undergraduate education is enriched by faculty participating in research. Research is essential to preparing graduate students for scientific careers in academia, government, and industry.

   We endorse graduate fellowships and traineeships. Students are quite responsive to perceived national needs in their selection of fields of research. The involvement of underrepresented groups should continue to be vigorously encouraged.

10. Successful research requires increasingly sophisticated instrumentation and facilities. We urge the NSB to maintain surveillance over the state of these national resources and to work for a national plan to keep them adequate for the conduct of pioneering science and engineering.

Education Recommendations

1. A major priority for the NSB and the NSF should continue to be education in science and engineering.

   NSF's support of education has a cascading influence. The Foundation should be at the leading edge of ever-emerging improvements in curricula, and methodologies of teaching and training for research.

2. The NSF should encourage further development of joint science, engineering, and management education programs.

This recommendation complements our previous research recommendations, which call for recognizing the importance and equivalence of scholarly research in a broader range of fields.

3. The Foundation is chartered to support improved education in mathematics and science throughout all the school years, from kindergarten through graduate and post doctoral studies. The two most critical areas needing improvement are K-12 education and undergraduate education.

   K-12 education, which prepares both the workforce and pre-professional students, must continue to receive the Foundation's serious attention and be pursued in collaboration with the Department of Education and other involved parties.

   The Commission urges the NSF to persuade the scientific community to expand its commitments to improving the quality of undergraduate education in mathematics, science and engineering. Introductory courses, especially, need improvement.

   We take note of the fact that the system has no one single weakness. No single grade or class can be neglected, for students fall away from science at all stages of the educational process. As we work any stage of the system, we must appreciate consequences throughout the system.

Structural Recommendations

1. Measurement of systems generates improved quality of operations. We speak here of something more than accounting and accountability. All reasonable measurements of the quality of the output of research, the quality of research allocation and the other principal functions of the Foundation should be subject to rigorous and common sense metrics for the evaluation and increase in the quality of its activities.

   Enlightened universities are beginning to teach and apply such measurement systems and both of these should be encouraged openly by the Board of the Foundation.

2. NSF should continue to support shared, common use facilities that cannot be built and maintained by individual institutions. Such facilities make economic sense and are an essential part of the research infrastructure for many individual investigators.

The Stronger National Policy

THE COMMISSION URGES that the role of the NSF be further clarified within an overall national policy, the goal of which should be to maintain the premier position of U.S. science and engineering while regaining America's lead in the commercialization of technology.

The first general recommendation reads: "The United States should have a stronger and more coherent policy wherein science and engineering can contribute more fully to America's strength." A call of this nature is not new. The strategy has been voiced in many terms—national science policy, national technology policy, and others. We do not emphasize a title. But, we do advocate a broad national policy going beyond science and engineering and including technology and its applications. The policy should be responsive to the voice and needs of society. NSF, with its emphasis on research in science and engineering and its complementary emphasis on education for science and engineering, will play a major, direct, and cascading role in fulfilling the overall policy.

The NSB, in helping to develop a national science and technology policy, should move quickly to propose a role for the NSF based on its past mission and a vision of what is needed today. In this plan the NSF should build on its accomplishments and strengths, specifically its partnership with the scientists and engineers of the nation's colleges and universities in developing outstanding research and strong science education; its partnership with the Department of Education and state and local governments working to strengthen science education in grades K-12; and its role in maintaining the nation's scientific infrastructure. The plan should include a response to the recommendations of this Commission in order to strengthen and make more effective the work of the NSF in meeting national goals.

The great strength of American science and of American universities is the absence of rigid cultural barriers between science and engineering and between pure research and its applications.

We urge that the Board and those involved in the planning resist any pressures to strip the NSF of its full spectrum of research goals and linkage mechanisms, from engineering research centers, to computer networks, to pure science and mathematics. The great strength of American science and of American universities is the absence of rigid cultural barriers between science and engineering and between pure research and its applications.

Throughout the report we have identified new challenges, evolving research fields, interdisciplinary opportunities, increasing dependencies among stages in technology development, grant size, student support, improved science education, knowledge diffusion and facility needs. The NSF will find it difficult to respond to these new challenges without an increase in resources, for the budget of the NSF already is inadequate to support its present responsibilities and programs.

Nevertheless, each recommendation is soberly, seriously and confidently proposed as being in the nation's best interest.

We are not unmindful that adoption of most of our individual proposals will increase the funds needed by NSF. We are equally mindful that controlled growth in federal funding and even deceleration of federal expenditures are options that must be considered by governmental officials and that policies to control spending need the support of the citizenry.

Yet, we do not equivocate in recommending each and the aggregate to the Board and through the Board to Congress, to scientists, to business constituencies, and to the broader public. Our recommendations are made in the spirit of continual improvement of a fine existing system.

Moreover, we are aware that the value of the output of the system can be multiplied within a "system of the whole" which would better make the essential linkages of education—discovery—development—application—competitiveness—quality of life.

To address this issue we urge that the NSF's responsibilities, as spelled out in its mission statement, and its budgetary needs be examined in the context of a newly conceived federal R&D budget that supports the stronger, broader policy. Reallocation of funds could achieve an energizing result that stimulates academic scientists and engineers, government officials, and people from industry to serve better the U.S. public. For we are convinced that ever improving universities and colleges and an ever more quality minded private sector working together can:

- lower the cost of improving the quality of life;
- add value throughout our society;
- create true wealth and opportunity for the country.

The hidden costs of not doing so may never be accounted for but would swamp the apparent cost of what is an energizing investment. So, we must get on with it.

However, all roads need not lead just to the public treasury. We have one additional suggestion—expanded contributions by business to complement public funding for selected science, engineering and technology programs.

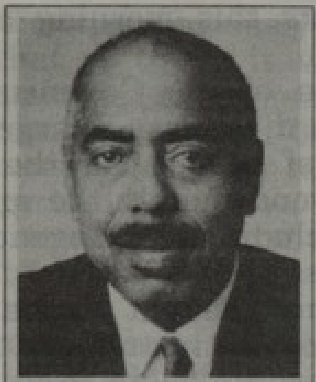
The Board and the National Science Foundation are today the lead organizations representing the interests of broad science and engineering in the United States.

It has been noted in other public documents that industry's basic research spending has lessened. Yet industry's spending for what is generally called R&D is substantial. Further, industry is moving to more affiliations—alliances, joint ventures, and consortia. Led and attracted by the visibility of a better integrated and more adequately funded government-university partnership, we see promise of a more willing contributing partner from among the progressive businesses of all sizes, including the smaller, higher growth companies where shared cost in programs with reasonable potential of eventual use would be welcomed.

Finally, the Commission returns to the role of the Board in influencing a stronger science and engineering and technology policy for the Nation. The Board and the National Science Foundation are today the lead organizations representing the interests of broad science and engineering in the United

States. The Board must work with its peers in the private and public sectors so that the nation might formulate a much needed science and technology roadmap. We are convinced that students, scientists, engineers, industry, and the public would join together to build and build on that roadway.

It is a journey we must begin.



Walter E. Massey
Director
National Science Foundation

James J. Duderstadt
Chairman
National Science Board

William H. Danforth
Commission Co-Chair

Robert Galvin
Commission Co-Chair

Mr. BOUCHER. Thank you very much, Dr. Duderstadt and Dr. Danforth. We appreciate your comments this morning and your recommendations.

I'm intrigued by the recommendation of the Commission, Dr. Danforth, that the National Science Board exercise a larger role in terms of recommending a broader set of policies for the Federal support of scientific research, going beyond merely the mission of the National Science Foundation, but including other agencies such as NIH and NASA and potentially others.

I wonder if your Commission gave any thought to the reasons that the NSF had not discharged this mission historically and considered whether there are legal barriers to its doing so in terms of the legislative charter of other missions that might preclude them from participating, or something of that nature, and whether you have any recommendations to us in terms of a legislative approach that might aid the National Science Board in achieving the goal of that larger policy formulation.

Dr. DANFORTH. Mr. Chairman, we tried to choose our words very carefully. Let me get at it this way: first of all, we really felt that there needed to be a Federal science and technology policy. Second, we felt that the National Science Board could be, ought to be an important participant in the development of that policy. And, third, because we were reporting to the National Science Board, we urged the National Science Board to call for such an effort.

We did not necessarily assume that the National Science Board by itself could undertake to do that effort. After all, we have the President's Science Advisor and the Office of Science and Technology Policy, and we have various other agencies. What we felt was that it should be done. And I should think—I would bow to your wisdom, but I should think that this committee could play a very important role. Now what the legal and legislative niceties are of how to do it I would leave to others.

Mr. BOUCHER. Okay. Dr. Duderstadt, would you care to perhaps enlighten us as to what the reaction of the National Science Board is to that specific recommendation and perhaps tell us why that mission has not been carried forth in the past. As you indicated in your statement, the Board does have a statutory mandate, or at least the power, to formulate those broader policies and recommend them to other policymakers within the Government. Why has that not happened in the past and what is your reaction as a Board to that recommendation?

Dr. DUDERSTADT. Let me first say the reaction of the Board has been very positive, and, indeed, we view this as one of the most important recommendations made by the Commission. And much of our time and effort over the course of the next several months will be spent examining the issues associated with the broader role.

As to why it hasn't happened in the past, it is—we've looked a bit at that. In part, it has to do with the Board's sense of responsibility for both oversight and policy development with respect to the National Science Foundation, which for a lay board is a significant responsibility. In part, there were issues, political issues; that is, the degree to which the Board took on a broader set of policy responsibilities, would that either distract us or put the National

Science Foundation in a difficult situation, if we had to take a stance on priorities, obviously?

Beyond that, I think it was a case that when the National Science Foundation, the organic legislation occurred, the world was much different, the Federal Government was much different, somewhat less complex, not as many agencies, not as many advisory groups. Nevertheless, it does appear that the Board not only has a statutory responsibility and mandate, but beyond that, is—has several characteristics that might well lend itself to these broader considerations.

The Board members are chosen from broad constituencies, representing higher education, the business community, various areas of science, appointed by the President, confirmed by Congress. They have terms of appointment six years in length that are, of course, comparable to those of the NSF Director and are quite long, and, therefore, would have that perspective.

I think there is a sense that if the Board were to assume the broader role, it would have to be in clear partnership with other bodies that are involved in Federal science and technology policy development. And, therefore, it would involve an extended dialog both with public leaders and with other Federal agencies.

I think some steps have been taken toward building those partnerships through the FCCSET effort, and so forth, that have occurred over past years, and right now the Board itself is beginning to explore among its members how it would build those broader partnerships.

But we see this as one of the most important recommendations of the report. It has been well received by essentially all members of the National Science Board, and it will be one of the principal areas of focus in our discussions in the months ahead.

Mr. BOUCHER. You do have, I think, a special responsibility. There is not another research agency that has the kind of advisory board or governing board that you have. It is, as you indicated, comprised of a large number of people who have diverse backgrounds and represent diverse constituencies, appointed by the President, confirmed by the Senate. The NIH does not have such a body. NASA does not have such a body. And the organic act passed in 1950 does charge you with that broader mission. So I think we would want to talk with you as we continue this dialog about ways that you might exercise that broader responsibility.

Dr. DUDERSTADT. We would welcome that.

Mr. BOUCHER. It strikes me as a way that you might be able to help us set priorities, and that is a critical need, as the Commission has acknowledged and others have indicated.

Let me take you to another area, and that is a recommendation in the report that the National Science Board achieve a balance between curiosity-driven basic research on the one hand and strategic research on the other. These are easy words to mouth; they're a little more difficult to implement.

How do you get to that kind of balance? Have you thought about how you might achieve that, and how will we as policymakers in the Congress know when you've reached that right balance? What kinds of measurements do you put in place, and what are your criteria? Dr. Danforth?

Dr. DANFORTH. I don't think, Mr. Chairman, that we conceive that there would ever be a final balance; that this is a shifting kind of arrangement; actually, that such an arrangement, of course, is already in existence in the National Science Foundation and also in the National Institutes of Health, in which it needs probably more explicit thought in the National Science Foundation.

There are already broad areas in which research grants are made to researchers. These areas ought to be reviewed regularly on a regular basis to see that the balance makes sense. I really don't know how you ever come to total agreement or have a measurement that will do it. But, for example, I mentioned that the National Science Foundation supports most of the research, basic research that is critical to understanding the environment better. And it seems to me this is an area, for example, in which funds are allocated, and it doesn't mean that one doesn't then put out proposals and people send in their proposals in the usual way, so that you're tapping the best minds of the scientific community. What it does mean is that you are seeing to it that some of the resources of the National Science Foundation are spent in this area.

We did not try and come up with a specific formula. I think this is very much a matter that involves both the judgment of national priorities and also the judgment by competent sciences on what will work. As one great scientist once said, politics is the art of the possible; so science is the art of the solvable. You have to put the money where you can expect to get results.

But it also has to be in areas of national need, and I really think that the National Science Board is well constituted to do that and, of course, would be then regularly presenting what they're doing to the Congress.

Mr. BOUCHER. Let me ask you, Dr. Danforth, to comment on one example that we have today of an attempt at least to arrive at some balance between undirected research, curiosity-driven research on the one hand, and better-directed research or strategic research on the other. And that is the FCCSET process itself, where certain interagency initiatives have been funded with the National Science Foundation being a significant contributor to those efforts.

How does that strike you and how did that strike your Commission members by way of a balance? Is that about the right balance or should there be more funds invested in strategic research than the current FCCSET process provides?

Dr. DANFORTH. Mr. Chairman, our committee met in only three official meetings, and we did not—we were generally positive about the FCCSET initiatives and thought of that as much in keeping with one of our—with the main recommendation for a broader national science and technology policy, but we did not go into the specifics. My own personal view is that that has been a very good initiative and should continue, and that those are good balances.

Mr. BOUCHER. Do you personally, Dr. Danforth, have any concern that if we add initiatives to the FCCSET process and, therefore, devote a larger share of the budgets of the various research agencies, including the National Science Foundation, to those efforts, that we run the risk of impinging unduly upon the basic research grants that are awarded to individual investigators?

Dr. DANFORTH. Yes, I do. I do have that concern. I think that, but I don't have a formula to offer you, Mr. Chairman. I think that is something that always has to be watched very carefully. It's a well-accepted truism, at least among scientists, that if one isn't careful, the more applied research can drive out the basic research and slow down longer-range advances. So I think I personally worry about that.

I will say, on the other hand, that if properly managed basic research can well go on within broad national policies, again, returning to the environment. One of the problems we have in dealing with the environment is not only perhaps lack of will in some areas, but the fact that we just don't know. We don't know what's going to happen. We don't know what's going on. And so that it is possible for basic research to be carried out under broad national initiatives. And the job of my colleague here and the National Science Board, and the leadership of the National Science Foundation, is to keep analyzing that and saying, "Where do we stand?"

Mr. BOUCHER. It all still basically falls within the broad category of basic research, even though we are directing that research somewhat. That's a step short of applying the research, but we're directly into these grant initiatives that still is within the category of basic research. I guess you would conclude, then, that we have not reached the point where the number of challenges and initiatives within the FCCSET process has intruded unduly upon the grants that the NSF can make for curiosity-driven research apart from these grant challenges? That's what lawyers call a leading question.

Dr. DANFORTH. Mr. Chairman, I would—I think I would agree with your statement, but I would add that we really felt—and we did not have the time to do as careful an analysis as we would like, but our collective judgment was that if you take the whole $75, $76 billion Federal R&D budget and you say, "What's best for the Nation," that we would think that more should be spent on the NSF type of activities than is now being spent; that there are plenty of good ideas and opportunities that would be of benefit to the Nation to be explored.

So while we're not—didn't have any current complaints about the balance, we had a conviction that the balance throughout the system, as the system is a whole, might be out of whack.

Mr. BOUCHER. Okay. Thank you, Dr. Danforth.

Dr. Duderstadt, would you care to comment on the question of balance between curiosity-driven and strategic research, and what the National Science Board might do in addressing the adequacy of that balance and making changes?

Dr. DUDERSTADT. Certainly. It was clear, even during the early days after the "Endless Frontier" report by Vannevar Bush, that a social contract was established in which public funds for the public good were used to support scientific research. While the identification of areas of key strategic national need is important to some degree in determining programs, the Foundation has found over the year that the public—over the years—that the public is best served when support is provided to the best people and the best ideas. Those can be within a framework, within a program that has a particular strategic focus, or those can be within programs that are broader, more basic in nature.

I think one of the issues here is that I don't think that the curiosity-driven activities of the Foundation have been negatively affected by the initiatives; for example, the FCCSET initiative, initiatives in global climate change, advanced materials, biotechnology, and so forth. But I would also hasten to add that the National Science Foundation is really one of the very few Federal agencies that has as its central mission the concern and the welfare of the fundamental research component of this Nation. At a time when the capacity of industrial R&D laboratories to conduct basic research, at a time when the Federal laboratories themselves, due to defense conversion and other issues, are seeing some erosion of that, the basic research responsibilities of the universities of this country become ever more important to the future of the Nation.

And, therefore, I think that means that that particular role of the Foundation becomes ever more important because it's a very unique role within the Federal Government. That's not to say that the Board is not attentive to achieving a balance and continuing to ask questions and monitor that balance. It has long been supportive and will continue to be supportive of strategic initiatives. There are others that can be taken on, but I think it also must be attentive to the fact that the National Science Foundation does have an important role to protect this very important source of fundamental ideas so critical to the future of the country.

Mr. BOUCHER. Let me just bring you to one other area of inquiry and then I'll yield to my colleagues. We have in the country today a national need estimated at something like $10 billion for research facilities. And that need is, by and large, going unmet. I've had university research administrators say that they have some of the most modern equipment that is available anywhere, highly costly equipment, that's being housed in buildings with leaking roofs, and they literally can't do much about that. That's the kind of circumstance in which a lot of individual investigators are having to operate today, and this is a need that we should address.

I need your advice on how we ought to do that. The National Science Foundation has an annual program of about $40 million for research facilities. At the same time, universities are persuading their Members of Congress to talk to the Appropriations Committee and obtain earmarks amounting to something like $700 million each year, and that strikes me as a rather inefficient way to decide how Federal funds ought to be spent with respect to university facilities. There ought to be some approach that is based on merit and on the consideration of where the dollars can receive the greatest return, if expended for research facilities.

And I would think the National Science Foundation's program would be the right place to do that because virtually everything you do, I guess everything you do, is peer reviewed.

What do you have to say to us, both of you, about the adequacy of the size of that research facilities program, some $40 million per year, addressing a $10 billion existing need? Should that be increased, and if it should be increased, can that be done at the expense of your basic research budget? In other words, what I'm looking for is a statement of in your view which is more important at this point, maintaining the research budget the way it is or increasing the budget for research facilities, making the assumption for purposes of this question that you're going to have constant dollars to work with? Dr. Danforth?

Dr. DANFORTH. I was waiting to hear what President Duderstadt—[Laughter]. Mr. Chairman, I wholly support your premises. I think that the facilities are a national problem. I believe that funding them, funding research facilities through special earmarks is a very wasteful way to proceed and that facilities should be, if funded by the Federal Government, should be peer reviewed.

I think we have a large backlog. I think that there are two—there are a number of ways that the Congress could address that backlog. You know, merely taking the money that's now going in earmarks and using that for a sensible, well-thought-out program would go a long way to helping with the problem.

The resources available to the National Science Foundation are not enough to make much of a dent. The recent report of the Commission reporting to the President's Science Advisor recommended a short-term setting aside of funds for a competitive program, and then looking to indirect costs in the long run as a way of keeping up and replacing facilities. Given the politics of indirect costs, I don't know if it's wise to rely on that.

If you asked me, Should that amount be taken out of the current funds for research to fix up the facilities, I would say let's delay and work toward a better solution. On the other hand, if you ask me, as I've heard proposed, Should the amount of money now going into supported facilities through the indirect costs be decreased to support more research, I'd say certainly not. I would not the funds in any way decreased. I'd rather see the earmarked funds spent better.

Mr. BOUCHER. Dr. Duderstadt?

Dr. DUDERSTADT. I certainly agree with Dr. Danforth. The needs are very urgent. The capacity of the states to support facilities and public institutions has deteriorated badly in recent years. The capacity of private institutions to put together private support, and so forth, is very limited.

The size of the earmark activity is a sign, I believe, of the urgency of the issue, the desperation many institutions face. I do believe this is a national problem and is now hindering the capacity of the universities to really provide the human resources and ideas needed by the Nation to address many of its major priorities.

Yet, I also fear that since it is such an enormous problem, to put that on a very small agency such as the National Science Foundation could very badly distort it. The concern of the National Science Board has always been that we view the facilities program within the Foundation as a drop in the bucket. As Dr. Danforth said, and I agree, it really would not go very far toward meeting the urgent and massive needs that now face us because of decades of neglect.

This has to be an effort across all Federal agencies, really across the entire Federal Government. And our concern within the Foundation is that we really, in the face of budget realities and our limited resource base, have to protect the dollars flowing to research even if it may be into research in inadequate facilities right now, and really try and make the case for much broader Federal policy that addresses theses infrastructure needs.

Mr. BOUCHER. When you make your annual submissions to the Office of Management and Budget, do you, as a National Science Board, recommend that substantial increases in funding for the facilities program be provided? And before you answer, let me just say I think you made a key point in your answer, and that is that one of the reasons universities go to their Members of Congress and ask for earmarks is because of the inadequacy of funding otherwise. And perhaps if you had a far larger program at the NSF, peer reviewing the various proposals and making awards where we get the biggest return for the dollar, you might find the universities doing somewhat less of that earmarking operation.

So do you ask for those larger funds when you make your request to OMB?

Dr. DUDERSTADT. We have requested larger funding for particular instrumentation needs. We have not established requests for major facilities as a major priority.

Mr. BOUCHER. Why not?

Dr. DUDERSTADT. And, again, the problem that we believe is that within the budget realities faced by the National Science Foundation, we think that if we were to do so, that could well come out of the hide of resources that are supporting our central mission, which is the support of fundamental research.

Mr. BOUCHER. Can I assume, then, from that answer that you believe the balance is about right within the dollars you have between research on the one hand and facilities on the other?

Dr. DUDERSTADT. Within the limited resources we have, we do believe that's the case for the Foundation, but we would also say across the Federal Government itself there's an urgent need, and this again is one of those areas where the National Science Board might be well advised to speak out more bluntly on national needs beyond those simply of Foundation programs.

Mr. BOUCHER. All right. I want to thank both of you for your thoughtful comments, and yield now to my colleague, Mr. Boehlert.

Mr. BOEHLERT. Thank you, Mr. Chairman.

President Duderstadt, I couldn't agree more that the Board might be well advised to speak out more on the national needs.

Those of you who bemoan the fact that the NSF budget is inadequate—and I couldn't agree more with you—what level would you recommend for adequacy, one, and, No. 2, where would you recommend we get the funding?

[Laughter.]

And there's a method to my madness—

Dr. DUDERSTADT. Yes.

Mr. BOEHLERT. —quite frankly. We have a very difficult time, at least I do—I don't know about my colleagues—I have a very difficult time when I get very distinguished witnesses like yourselves who know so much and have so much to offer, a very difficult time getting guidance from the witnesses on priorities. I mean, do we do everything at once? Of course, we can't do everything at once. You talk about a facilities program of $40 million. I mean, that's a petty cash fund. That's, you know, putty, stuff like that.

Tell me what level you think would be adequate, and then address the very sensitive issue of where we might be able to get that.

Dr. DUDERSTADT. I think in the near-term the first objective should be to really achieve the goals set by both the earlier administration and reinforced by the present administration, and supported by the Congress, of doubling the Foundation's budget. That doubling envelope over five years, that goal which was set several years ago, we're about halfway toward, but because of budget realities we've had some difficulty moving toward that. And I think that goal was well considered and that should be the initial target.

Beyond that, it really has to do in part with the role that you see for the Foundation. If you wish the Foundation to move into some of these areas associated with strategic national issues and needs—and I personally believe that if we were to do so, it should be done in partnership with other Federal agencies rather than simply within the Foundation alone. Clearly, additional resources will have to be found.

As to where those come from, I suppose that you could identify some of the logical targets that people are looking at today, whether it's defense conversion, through reallocation from other near-term issues, but I think in my mind the real issue that you have to address is, I view the Foundation as an investment in the future, and many of the particular resource needs, compelling though they may be in front of you, as needs for the present. And it really has to do with how you strike an appropriate balance between investing for the future of this Nation and investing and meeting its present real and urgent needs.

It's a very difficult thing to do, but, in my mind, the Foundation itself is so critical to the future of the Nation over the longer term that it merits that kind of priority and reallocation.

Mr. BOEHLERT. So when you're saying we're about halfway there, the budget recommendation is $2.7 billion and you'd be basically content dealing in the real world with another billion?

Dr. DUDERSTADT. No, what I'm saying is that the original doubling pattern that we had I believe would take the Foundation to a number that's—what?—on the order of $4 to $5 billion, or something like that, a year. That was a target that was set several years within an existing set of missions and responsibilities. And I think that is a suitable target for that set of missions. If, in fact, additional missions are to be taken on, then further resources will be needed to accomplish those.

Mr. BOEHLERT. Dr. Danforth?

Dr. DANFORTH. Our Commission debated these issues and debated whether to try and answer your question directly at the moment. And we felt that in the time that we had allowed that we could not do that adequately, but we thought this: we thought the Nation's total R&D budget, $75, $76 billion, ought to be looked at as a whole and then ask: what proportion of this total effort should be spent on the work of the National Science Foundation or that sort of thing? What should be spent on facilities?

And our collective judgment was that enough money could be found within that, if you set priorities within that whole $76 billion, to do the things that President Duderstadt was talking about.

Now we're not totally naive about how different committees have different responsibilities and different agencies, but we do think that there is money spent on R&D that, if looked at in a total way, could be better spent.

Mr. BOEHLERT. Well, I don't think there's any question about that. We would warmly embrace that, but I guess I'm looking for something a little more definitive as you give me guidance.

Seventy-six billion dollars, right? You can't create money out of thin air, so then you're talking about reallocating and that's one of the things that I've been talking about—

Dr. DANFORTH. Right.

Mr. BOEHLERT. —to anyone who would listen. And that's one of the reasons why I get into things like the SSC, for example. And I don't want to go off on a tangent about that, in deference to my colleague from Texas and my chairman, but that's a clear example. I mean we're going to spend $647 million this year on the SSC and we're spending one-fifteenth of that for facilities. I mean, it's just crazy, but another subject for another day.

One of the things the chairman and I are talking about is having some joint hearings with Mrs. Schroeder, who is chairman of the Armed Services R&D Subcommittee. And I notice your report is rather silent on what we might be able to do in concert, in partnership with defense laboratories. I mean, some people are saying, "Hey, the cold war is over and just close down these defense laboratories and take the money and put it elsewhere." Well, we can't do that; you know that and I know that.

But I think there's a great deal more we can be doing in a collaborative effort. Would you address that general subject, President Duderstadt?

Dr. DUDERSTADT. I think that's terribly important because it's clear that a small Federal agency like the National Science Foundation itself really cannot take on some of these very important challenges alone. It really has to partner.

Now we've had great success in partnership, for example, with K-12 science and math education with the Department of Education. We have good relationships with the Department of Defense through DARPA, and so forth, looking at some of the issues that are being raised by defense conversion; strong relationships with NIST on issues of technology-driven economic development, and those are appropriate and I think should be expanded.

One of the interesting ways to think about this is to think of the National Science Foundation as one of the principal conduits or windows on the great intellectual resources represented by America's university system. And if you look at the Foundation as essentially a bridge that other components of the Federal Government, including the national laboratories, could use to develop relationships with those universities, I think you might move in the direction that you've suggested.

In a sense, the Foundation has in the past and can play a middle man in brokering those relationships with other parts of the Federal Government that have not established such a far-reaching and intimate relationship with American higher education. That's a great strength of the Foundation, and that strength is one that I think could well serve all the Federal Government right now.

Mr. BOEHLERT. Let me just follow through, Dr. Danforth, before I get to you. Am I naive to think in terms of sometime in the future—we talk about the facilities needs. Some of the greatest facilities are owned by the—

Dr. DUDERSTADT. Exactly.

Mr. BOEHLERT. —the Pentagon. And am I naive to think in terms of in the future, in the not-too-distant future, those facilities being utilized where you might have DOD researchers working side by side with non-DOD researchers? Is that something that is realistic?

Dr. DUDERSTADT. I think it's not only realistic, I think it's going to be absolutely necessary because we cannot afford the duplication of those extraordinary facilities on each university campus in America. They are there and they should be utilized. The universities can provide human resources. We can provide access to education, which of course is our fundamental mission, beyond simply the research itself.

I might say that there is a long precedent for, and tradition for, such relationships within the Department of Energy with the National Atomic Energy Laboratories. Universities have worked side by side with the major atomic energy laboratories throughout this country for decades in which university scientists and students worked side by side with Federal scientists, many of whom are involved in defense work, many of whom are involved in civilian activities, but making use of both human and facilities resources at those laboratories. It's worked very, very well, and I think those patterns could well be extended to other national laboratories, Federal laboratories.

Mr. BOEHLERT. Dr. Danforth, do you have any comments in general on this?

Dr. DANFORTH. I agree. I agree with what's been said. Whenever one thinks of conversion, though, it's always well to remember it's harder to do than to say.

Mr. BOEHLERT. Exactly. Well, one of the things I'm trying to do—and I'm privileged in my district to represent a premiere DOD research facility, the Rome Laboratory. The Air Force went through an extensive review of all its laboratory facilities and consolidated 14 labs into 4 super- laboratories, and one of them is in Rome, New York. So I say to myself one of the world class research facilities—and there are all these universities around there; why not have the university come and work in cooperation with Rome laboratories? So I'm working on that right now, to bring that about, and have set up a meeting with all the universities and the Rome lab people, and they're doing a much better job.

Why, for example, do we need one more—my university friends won't agree with this, but one more laboratory at Cornell or at Syracuse or at RPI or at RIT or at Clarkson, if we already have in the neighborhood a world class facility that could be used by those researchers, if we had the right agreement? So that's the type of thing that I am encouraging.

Let me ask you one further question. The report is almost silent on K through 12 education, and, I mean, you build a structure from the foundation. Would you elaborate on K through 12 education?

First of all, why was it silent? Do you agree that it's critically important or do you think it's being well taken care of? Dr. Danforth?

Dr. DANFORTH. I think, sir, that the report did not intend to be silent on K through 12 education. We tended to be very supportive of the role of the National Science Foundation in education and across the board from kindergarten through graduate education. We did not see that as a controversial issue and didn't spend a lot of time on it, and perhaps shortchanged it in the report. But it wasn't through lack of appreciation of its importance or the role of the National Science Foundation.

As I said in my remarks, the funding of the National Science Foundation education programs which are directed toward K through 12 through math and science is very small compared with the funding of the Department of Education, but the cooperative efforts that have been mentioned have made that very small allocation of funds very, very effective, for the National Science Foundation does have a window on the science and mathematical minds that can make major contributions to the teaching of those particular subjects.

Mr. BOEHLERT. But we're not sure—

Dr. DANFORTH. If we shortchanged it, we didn't intend to and we should not have.

Mr. BOEHLERT. Yes, because we're not doing nearly as well as we should be. I mean, I'm alarmed, as I'm sure most people are, every time you pick up another weekly news magazine or The New York Times or one of the publications, reporting that in international competition our kids don't measure up with their counterparts in other parts of the world in terms of math and science proficiency. And then I'm alarmed when I heard, as I did a couple of years ago—and I don't know if this has changed; I doubt it—when one of the witnesses at one of the hearings said that 50 percent of the youngsters in America's public school system K through 12 are taking science from teachers who are not certified to teach science. Those things bother me. And I'm trying to find out, figure out a way to improve the situation.

Senator Rockefeller and I a couple of years ago got through some legislation creating a science and math scholarship program, and it's one of those, I think, great ideas and we got the authorization legislation; we haven't got the first buck through yet. And, essentially, what we're proposing—and it's now called the "Noise Scholarship Program." It's a law of the land, but no funding.

What we do, on a pilot basis, we take college students in their junior and senior year who are majoring in science, math, or engineering, give them $5,000-a-year stipends in exchange for an agreement that they would teach for two years in the public school system for every year of the stipend. That helps the youngsters finance very expensive education. That assures us that we're at least going to get some people going from the college campus into the classroom to teach in these disciplines.

Can we get the National Science Board to speak out loud and clear in support of this program?

Dr. DUDERSTADT. I think you could. I think over the last several years the National Science Foundation and the National Science Board have viewed math and science education as really one of the highest of priorities, both. The rapid growth of the K-12 math and science education programs, stimulated to a considerable degree by the very strong interest on the part of Congress, I think, has demonstrated a strategic area in which the National Science Foundation can have great impact.

We've always viewed our impact, however, as one of both leadership and leverage because, while somewhat over $400 million is going into math and science education today, it's significant within the context of the National Science Foundation; it's small compared with resources flying into education around the country.

So there, again, is a strategic opportunity for partnering, partnering with the Department of Education, partnering with the states, which is now being done through the Statewide Systemic Initiative Program of the National Science Foundation, in a way to leverage the impact. With the intellectual resources coming through Foundation programs, but the real resources and the actual impact occurring working with the states and with the communities. This is an issue of great importance and great priority to the Foundation that has been very strongly supported by the Board, at least during my years on it, and I think continues to grow in support.

Mr. BOEHLERT. I would appreciate from you, if I could get it, a pledge that you discuss this at a future Board meeting and then follow through with a letter to the President to let him know, or at least to Jack Gibbons, because this is—I mean, everybody I talk to says it's a wonderful idea. Jay Rockefeller gets the same reaction when he talks to people, and yet there's no funding provided.

Ms. DUNN. We'll have our—one of our two standing committees is on education and human resources for the National Science Board and I'll make certain that they consider this.

Mr. BOEHLERT. And just, finally, Mr. Chairman, I appreciate your indulgence. The $400 million is large in terms of the context of the NSF budget, which I think should be much larger, but it's a drop in the bucket—

Dr. DUDERSTADT. Exactly.

Mr. BOEHLERT. —nationally for science and math education, for the challenges of the 21st century. I mean, I want every youngster in America to be computer literate by the sixth grade. How are they going to be computer literate if they don't have computers in the classroom? And they cost money. So I appreciate the good work you're doing. I just want you to do more of it, and I want you to be available all the time to guide us. Thank you.

Mr. BOUCHER. Thank you very much, Mr. Boehlert.

The gentlewoman from Texas, Ms. Johnson.

Ms. E.B. JOHNSON OF TEXAS. Thank you, Mr. Chairman.

As I have listened, I've had some ideas and some questions. Firstly, I wonder how much coordination do you do between the agencies as it relates to science education.

Dr. DUDERSTADT. I think that there has been a very significant growth in that coordination/cooperation in recent years. Luther Williams, who's the Assistant Director of the Foundation for Education and Human Resources, also wears that hat on the FCCSET Committee, has had strong relationships with not simply the Department of Education, but with other Federal agencies which have concern and programs in education and in training.

That is a developing relationship. It's based upon a sense of cooperation and confidence among the agencies, but we think the FCCSET process has really taken the Foundation a long way toward achieving that, and I think that the trends that we see right now are exactly in the direction that they should be.

Ms. E.B. JOHNSON OF TEXAS. I think probably in terms of coordination and consolidation, the laboratories at Rome, New York, would fit very well with the National Science Laboratory at the Supercollider site, where the State of Texas puts in at least a billion dollars, and it's coordinated with the medical school there in Dallas for research, as well as elementary schools and other levels of public education.

We have a medical school of the first class. I think it's about eight—seven or nine Nobel Prize winners in research, medical research, in the country; half of those are at this University of Texas Southwest Medical School. So I should think that what I need to do is move rapidly to have that Rome, New York research lab to join us so they can certainly reach a higher level of achievement.

Thank you.

Mr. BOUCHER. Is that all, Ms. Johnson?

Ms. E.B. JOHNSON OF TEXAS. Yes.

[Laughter.]

Mr. BOUCHER. Thank you.

Ms. E.B. JOHNSON OF TEXAS. We'll finish it up on the budget.

[Laughter.]

Mr. BOUCHER. Thank you very much.

Well, the subcommittee expresses its appreciation to both of these witnesses for their excellent presentations this morning, and I'm certain that as we continue this inquiry we'll be calling on you for additional advice. Thank you very much.

Dr. DANFORTH. Thank you.

Dr. DUDERSTADT. Thank you.

Mr. BOUCHER. We'll welcome now our second panel: Dr. Daniel Nathans, a member of the PCAST Committee on Research-Intensive Universities and university professor of molecular biology and genetics at Johns Hopkins University School of Medicine in Baltimore. He is also a former Nobel Prize winner.

And Dr. H. Guyford Stever, the chairman of the Carnegie Commission Task Force on Establishing and Achieving Long-Term Goals. He is a former Director of the National Science Foundation and a former National Science Advisor.

Dr. John Wiley, member of the National Academy of Sciences Working Group on the Academic Research Enterprise and dean of the Graduate School of the University of Madison—University of Wisconsin at Madison.

And Dr. Brian M. Rushton, president of the Industrial Research Institute and senior vice president for research and development at Air Products and Chemicals, Incorporated, in Allentown, Pennsylvania.

Dr. Nathans, we'll be pleased to begin with you this morning.

And let me say to the entire panel that your written testimony will be made a part of the record, and we would welcome your oral summary of that testimony and would ask that you keep it relatively brief so that we'll have time to propound questions.

Dr. Nathans?

STATEMENT OF DR. DANIEL NATHANS, MEMBER, PCAST COMMITTEE ON RESEARCH-INTENSIVE UNIVERSITIES, AND UNIVERSITY PROFESSOR OF MOLECULAR BIOLOGY AND GENETICS, JOHNS HOPKINS UNIVERSITY SCHOOL OF MEDICINE, BALTIMORE, MARYLAND; ACCOMPANIED BY DR. H. GUYFORD STEVER, CHAIRMAN, CARNEGIE COMMISSION TASK FORCE ON ESTABLISHING AND ACHIEVING LONG-TERM GOALS, WASHINGTON, D.C.; DR. JOHN D. WILEY, MEMBER, GUIRR WORKING GROUP ON THE ACADEMIC RESEARCH ENTERPRISE, AND DEAN OF THE GRADUATE SCHOOL, UNIVERSITY OF WISCONSIN- MADISON, MADISON, WISCONSIN; AND DR. BRIAN M. RUSHTON, PRESIDENT, INDUSTRIAL RESEARCH INSTITUTE, AND SENIOR VICE PRESIDENT, R&D, AIR PRODUCTS AND CHEMICALS, INC., ALLENTOWN, PENNSYLVANIA

Dr. NATHANS. Mr. Chairman, I thank you for the opportunity to discuss the mission of the National Science Foundation in relation to the report of the President's Council of Advisors on Science and Technology entitled, "Renewing the Promise: Research-Intensive Universities and the Nation." Since the subcommittee is familiar with the PCAST report, I won't summarize it here, but get to some of the issues you asked me to address.

The PCAST report has a number of recommendations that have relevance to the policies of NSF, and, indeed, of all Federal agencies that are partners with universities in fostering scientific research and education in the national interest.

In general terms, the PCAST report supports the basic mission of NSF as stated in the Commission's report. A central recommendation of the PCAST report is that, "The Nation continue to invest enough in basic research to sustain world class accomplishments in all major areas of science and technology." This is at the heart of the NSF mission.

The report has more specific recommendations to achieve this end that are relevant to NSF, such as paying the full cost of university-based research, including indirect costs, and investing in modern facilities and equipment for research at universities. Another major recommendation is to give more emphasis to teaching and to attracting the best scientific talent to careers in science or engineering. Here, again, these have been longstanding goals of NSF. We believe they should be given greater emphasis both by NSF and by universities.

A third recommendation is to move scientists and students between industry and universities as the single most effective way to break down barriers between these two cultures. And we note that the National Science Board Commission proposed that NSF help to facilitate such an interchange.

Finally, a major theme of the PCAST report is the need for research-intensive universities to adapt to a constrained resource environment. In our view, universities should be committed to meeting world class standards in all of their science programs and should eliminate or downsize weaker programs and departments rather than trying to cover everything.

To the same end, PCAST recommends that Federal funding agencies, such as NSF, should not encourage universities to embark on new programs or facilities when there is little or no long-term prospect of sustaining them. This has happened in the past and is one cause of some of the problems universities now face.

I would like now to comment on the report of the National Science Board Commission not only in the context of the PCAST report, but also from the perspective of a university scientist. I strongly agree with the key recommendations of the Commission. First, there is a pressing need for an overall national science and technology policy of which the mission of NSF is a part. Considering the mission of NSF outside a comprehensive policy framework has led, I believe, to extravagant expectations of the agency and dilution of its resources.

Second, the mission of NSF should be to support research on the frontiers of knowledge, including the education of scientists and engineers. Of all the Federal agencies supporting science, NSF should be the one with the longest view, the one that nurtures talent and encourages the most creative research. This is a vital mission for the Nation.

Like the Commission, I do not see a sharp separation in many fields of science between frontier research in science and development of technology. In my own field, molecular genetics, the technology that is now the foundation of the biotechnology industry came from research aimed at understanding the fundamental chemistry and action of genes.

Third, I want to comment on the Commission's recommendations on education. The best science and technology policy will fail without talented scientists and engineers. There is enormous talent in our country. Yet, a high percentage of advanced students in mathematics, science, and engineering in our universities are from other countries. NSF and other agencies must do far better in attracting talented American youngsters to science and keeping the best of them in science through graduate school.

Finally, I return to a point made earlier: NSF's mission should fit into a broad Federal policy on science and technology. It should not be assigned so much that it falls short in its primary mission of advancing the frontiers of knowledge in science and engineering.

Thank you.

[The prepared statement of Dr. Nathans follows:]

Statement by Daniel Nathans before the Subcommittee on Science of the Committee on Science, Space, and Technology of the U.S. House of Representatives, March 3, 1993.

(Daniel Nathans is University Professor of Molecular Biology and Genetics at the Johns Hopkins University School of Medicine and Senior Investigator of the Howard Hughes Medical Institute. He shared the 1978 Nobel Prize in Physiology or Medicine for his research in molecular genetics. Dr. Nathans served on the President's Council of Advisers on Science and Technology (PCAST) from 1990 to 1993.)

Mr. Chairman, I thank you for the opportunity to discuss the mission of the National Science Foundation in relation to the report of President Bush's Council of Advisers on Science and Technology entitled "Renewing the Promise: Research-Intensive Universities and the Nation".

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First, there is a pressing need for an overall national science and technology policy of which the mission of NSF is a part. Considering the mission of NSF outside a comprehensive policy framework has led, I believe, to extravagant expectations of the agency and dilution of its resources.

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Finally, I return to a point made earlier. NSF 's mission should fit into a broad federal policy on science and technology. NSF should not be assigned so much that it falls short in its primary mission of advancing the frontiers of knowledge in science and engineering.

Copies of the Report Renewing the Promise: Research-Intensive Universities and the Nation can be purchased from:

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Renewing the Promise: Research-Intensive Universities and the Nation

A Report Prepared by the

President's Council of Advisors on Science and Technology

December 1992

66-821 0 - 93 - 3

The Council provides private sector advice to the President in matters of national importance involving science and technology. The Council responds to requests from the President and aggressively maintains a general watch on developments to be in a position to raise issues, opportunities, and concerns to the President. The issues that the Council addresses normally affect not only the private sector but cut across Federal Department and Agency boundaries. In addition to being fully responsive to the President, the Council considers requests made by the Vice President and others within the Executive Office of the President.

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Superintendent of Documents, Mail Stop: SSOP, Washington, DC 20402-9328
ISBN 0-16-038257-2

Renewing the Promise:
Research-Intensive Universities and the Nation

A report prepared by the President's Council of Advisors on Science and Technology

December 1992

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THE WHITE HOUSE

WASHINGTON

November 23, 1992

Dear Mr. President:

I have the pleasure of transmitting to you, on behalf of the President's Council of Advisors on Science and Technology, our latest report, *Renewing the Promise: Research-Intensive Universities and the Nation*. For this study, we considered research-intensive universities as the approximately one hundred and fifty institutions that conduct a significant share of our country's basic research and that produce our country's leading scientific and engineering talent. This makes them the foundation of the nation's science and technology enterprise.

The "promise" refers to the vision contained in Dr. Vannevar Bush's 1945 report to President Truman: that our leading universities, with strong public support, could generate the intellectual and human capital that would, in turn, enable the United States to become a more prosperous, healthier and more secure Nation. We followed that vision and the extraordinary accomplishments of the United States over the past half-century -- in technology and industry, in medicine and health, in agriculture and management of our environment -- attest to the fulfillment of the promise.

In our rapidly changing world, the United States faces ever increasing economic and technological challenges and environmental, public health, and national security concerns that differ from those of the past. The Council believes that, more than ever, our Nation will depend on its colleges and universities for the generation of the new knowledge and talent needed to maintain world leadership. The "promise" must be renewed.

The Council is concerned, however, that the relationship between the Federal government and the research-intensive universities is under stress, and that the universities are not as well-positioned as they should be to help meet the Nation's future needs.

In its report, the Council identifies weak points in the system and suggests some corrective measures for universities and Federal agencies, as well as state governments, industry, and other supporters of universities. We believe that these recommendations, if followed, would go a long way toward re-strengthening the universities and enabling them, in partnership with the Federal government, to make the greatest possible contribution to the Nation.

The Council believes that the issues raised by the report are of fundamental, non-partisan importance. We hope, therefore, that you will not only find the report helpful to your own thinking about the long-term interests of the Nation, but that you will commend it to the President-elect for his consideration. Furthermore, if you agree, the Council will release the report to the public. It should stimulate a healthy national debate on the issues.

Although the Council concluded that the U.S. research and development (R&D) system is basically sound and continues to serve us well, we feel that there is also a need to look beyond the issues addressed in this report. Just as the end of World War II was an opportune time for Vannevar Bush and his colleagues to looked ahead at the role of R&D in our national life, the end of the Cold War warrants a new examination of the Nation's R&D system: its rationale, goals, organization, funding and administrative mechanisms.

We believe that the Council should begin to undertake such a re-examination as soon as possible. Here, too, we hope that you would urge the President-elect to instruct his Council to follow such a course in the interest of the Nation.

This report views the relationships between the Federal government and the research-intensive universities from the outside. I am transmitting to you, in parallel with this report, a companion report prepared by an interagency working group of the Federal Coordinating Council for Science, Engineering and Technology (FCCSET) that views these relationships from inside the Federal government. Together, they represent a comprehensive review of this important area.

Sincerely yours,

D. Allan Bromley
The Assistant to the President
for Science and Technology
and Chair,
President's Council of Advisors on Science and Technology

The President
The White House
Washington, DC 20500

Enclosure

EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF SCIENCE AND TECHNOLOGY POLICY
WASHINGTON, D.C. 20506

November 18, 1992

Dear Dr. Bromley:

We are pleased to transmit to you the report on Research-Intensive Universities, entitled *Renewing the Promise: Research-Intensive Universities and the Nation*, produced by the President's Council of Advisors on Science and Technology (PCAST).

The report focuses on a particular class of institutions, the research-intensive universities, because of their particular role in the nation's Research and Development (R&D) enterprise. Because of their important relationship with the Federal government, the health and future of those universities are inherently of significant concern in public policy matters. But our focus in no way implies that other types of institutions of higher education do not play critical roles in the larger educational system, particularly as recruiters and developers of the nation's talent.

The issues facing us are numerous and complex. We have sought to identify those that are the most pressing but that can be addressed in a realistic fashion, as well. Some of our findings and recommendations may not be popular, but a positive future sometimes requires painful treatment. At the very least, we hope that the report will stimulate and contribute to a healthy public debate. Given the critical nature of the present situation, we hope that our recommendations will lead to a productive readjustment of the current system.

We have also recommended a next step. Beyond the immediate issues, there is a need for a very fundamental look at the place of R&D in our nation's future and how it should be planned, supported, carried out, and managed. Such a recommendation should be high on PCAST's agenda at the outset of the new Administration.

Sincerely yours,

David Packard
Chairman, Committee on
Research-Intensive Universities

Harold T. Shapiro
Vice-Chairman, Committee on
Research-Intensive Universities

Enclosure

The Honorable D. Allan Bromley
Assistant to the President for
Science & Technology
Executive Office of the President
Washington, DC 20500

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PREFACE

Earlier this year, the President's Council of Advisors on Science and Technology (PCAST) turned its full attention to a core component of the nation's science and technology enterprise: those institutions of higher education that produce simultaneously the bulk of America's most highly trained scientists and engineers and a substantial fraction of our country's new scientific knowledge. Because most faculty at those institutions devote considerable efforts and resources to research as well as teaching, we refer to them as "research-intensive universities." The term applies to somewhat more than one hundred and fifty universities from among more than three thousand institutions of higher education. Their direct and indirect contribution to our national well-being — economic growth, international competitiveness, and new jobs — is immeasurable.

For more than four decades, the research and the graduate and post-doctoral education capabilities of those universities have rested in large part on support from the federal government. Because the research-intensive universities both benefit the public and are supported by it, their health and productivity are key matters of public policy.

As we look to the future, we are convinced that America cannot continue to meet the challenges of international economic competition, of national security in a post-Cold War world, and of threats to the environment and to public health without the continued contributions of the research-intensive universities.

As the present time, however, we are concerned that America's research-intensive universities are not as well prepared as they should be to assume the responsibilities of the future. We are also concerned that the American public no longer has the confidence in the research-intensive universities that will enable those institutions to bear those responsibilities. This is not a healthy situation for the nation.

Thus, we have sought to identify the weak points that threaten the otherwise strong web that binds together the federal government and the tax-paying public with the research-intensive universities into a major scientific research and higher education partnership. We have also considered the relationship between universities and industry — one that is also critical to the nation's future. In this report, we present our findings and recommendations for strengthening the overall enterprise.

Our approach to the subject consisted of three parts. First, the Council took the unusual step of constituting itself as a committee of the whole for the project. We felt from the outset that the study required the widest possible range of institutional and scientific perspectives and experience: industrial, governmental, and academic and from the physical, natural, life, and social sciences and engineering.

Second, we solicited — and received — a wide range of information and views from various interested parties. At six meetings around the country we heard from undergraduates, graduate students, post-doctoral students, and untenured faculty members as well as senior faculty and university administrators. We heard views representing a cross-section of universities — large and small, public and private. Just as important to our findings, we gathered perspectives from four-year and two-year institutions and from minority institutions, all of which play critical roles with respect to the research-intensive universities. Representatives from companies in the areas in which our public meetings were held rounded out the picture, as did representatives of educational and scientific associations. Written comments were also received from a wide variety of individuals and institutions responding thoughtfully to our invitation to provide input and advice.

This public input was invaluable to the study. We express our deep gratitude to the many who so graciously hosted the meetings, who participated in them, and who sent us their observations and ideas. Without these contributions, many of our findings would not have emerged so clearly, if at all.

Third, we benefitted greatly from data and perspectives provided by a group of federal agencies whose policies and programs affect research and education. Meeting as an Ad Hoc Working Group on Research-Intensive Universities and the Federal Government of the Federal Coordinating Council for Science, Engineering, and Technology (FCCSET), they conducted their own study in parallel with ours. The Working Group is chaired by Deputy Secretary of Education David Kearns, with National Institutes of Health Director Bernadine Healy and National Science Foundation Director Walter Massey serving as Vice-Chairs. We are greatly appreciative to the FCCSET group for sharing its views and for the data and information it has provided. Any interpretation of those data in this report is, of course, our own.

Finally, we would be remiss indeed were we not to recognize the vital contribution made to this report by many members of the Office of Science and Technology Policy and PCAST organizations. In particular, our thanks go to Pierre Perrolle, William Raub, and James McCullough for outstanding staff work throughout this activity. We would also thank Alicia Tenuta and Philip Bolus for major contributions to the structure of the entire study, the organization of the public meetings, and the production of the report.

Executive Summary

Introduction

Vannevar Bush's 1945 report, *Science — The Endless Frontier*, promised the nation the possibility of a prosperous, healthy, and secure future if the United States made a substantial commitment to basic research. Bush proposed specifically that the federal government provide funds to the nation's colleges and universities so that they could generate new knowledge and scientific and engineering talent. That vision led ultimately to the establishment of the largest and strongest scientific and higher education enterprise that the world has ever seen.

The human and intellectual capital generated by U.S. colleges and universities over the past four decades has been the basis for a vast array of accomplishments that have touched the lives of all Americans: jobs in new industries; sophisticated consumer products; technological breakthroughs affecting transportation, communications, and entertainment; an abundance of food; advances in medicine and public health; increased security against the threat of nuclear annihilation; and improved protection against natural disasters and environmental degradation. The American taxpayer's investment in university-based research has paid off handsomely. The 1945 promise has been more than fulfilled.

Those accomplishments notwithstanding, the relationship between the American public and institutions of higher learning is showing serious signs of stress. This partnership of over one hundred and fifty research-intensive universities and the federal government has grown to be a research and educational enterprise of enormous size, scope, and complexity. Despite their success, or perhaps in part because of the ever increasing expectations derived from that success, universities are losing public confidence. The many partners in the overall enterprise — students and parents, the federal and state governments, foundations and industry, and faculty and scientific communities — increasingly are expressing discontent with the enterprise's current state and direction.

The problems underlying that discontent must be addressed. In today's rapidly changing world, the United States is confronted with shifting national security needs, increasing economic and technological challenges from other countries, and new environmental and public health concerns. If anything, America's dependence on its colleges and universities both for creating new knowledge and for training new talent is greater now than at any time in our history.

In reviewing the health of the nation's research-intensive universities and their relationship with the federal government, PCAST has focused on six main areas:

- the implications of a limited resource environment;
- the fundamental importance of teaching activities at research-intensive universities;
- the erosion of public trust and confidence in our universities;
- federal investment in university-based research;
- interactions between universities and industry;
- and the identification and development of exceptional talent for science and technology.

Findings and Recommendations

I. A Matter of Limits: Adapting to a New Resource Environment

Advancing the frontiers of knowledge is not, as it once may have been, a matter of intellectual luxury. In an era of relentless global economic competition, it is a national imperative. The United States must continue, as a nation, to invest in fundamental research. The returns on such research, although unknowable in advance, have proved enormous in the past and are likely to be even greater in the future.

A realistic assessment of the next several decades indicates, however, that no matter how firm our national resolve may be to invest in the future, resources will not expand as rapidly as our intellectual capacity to pursue promising research opportunities. It is unreasonable to expect that the system of research-intensive universities will continue to grow as it did during periods in the 1960s and 1980s.

The cross-pressure of expanding opportunities and constrained resources poses a risk for the United States: spreading its resources too thinly across its array of highly trained investigators and research-intensive universities. Most of our research-intensive universities aspire to excel in all or most areas of scholarship and education. As worthy as those aspirations might seem, they are likely to be ill-advised. They cannot be fully realized in an era of significantly constrained resources.

The relentless quest for an ever broader range of activities will inevitably destroy the most important aspect of American higher education and research — quality. We cannot afford to allow our higher education to decline to the levels of mediocrity that now characterize much of our precollege education.

So that research-intensive universities may continue to function productively in an environment of limited resources, PCAST urges them to:

> adopt more highly selective strategies based on a realistic appraisal of the future availability of resources and a commitment to meet world-class standards in all programs that are undertaken.

Such strategies will require universities to:

- eliminate or downsize some departments and specialties rather than sustain less than world-class activities in every area of science and engineering;

- collaborate with other academic, industrial, and governmental institutions in sharing instructional and research facilities and programs;

- build facilities or programs only where there are strong long-term prospects of sustaining them; and

- develop permanent institutional mechanisms for strategic planning that will foster a balance between activities and resources and among teaching, research, and other missions that are commensurate with society's values and the needs of the universities.

PCAST also urges federal agencies and other supporters of research-intensive universities to:

- refrain from encouraging universities to embark on new research or education programs or the building of facilities when there is little or no long-term prospect of sustaining those programs; and

- refrain from developing or implementing research or education programs that would increase the net capacity of the system of research-intensive universities.

II. A Matter of Education: The Importance of Teaching at Our Universities

More than ever in its history, America needs its institutions of higher education to train scientists and engineers and educate citizens who can fill increasingly technical jobs. It also needs them to educate citizens of a democratic society who can understand the principles of technologically-oriented public policy issues. Furthermore, it is essential that colleges and universities continue to adapt to the increasingly diverse educational paths of many of our citizens, and keep pace with their desire and need for life-long learning. Finally, U.S. scientists and engineers must be capable of working in an international environment, in which foreign language skills are very important.

Many higher education institutions, including research-intensive universities, are turning away from their educational mission, particularly from undergraduate education. We believe that many of the complaints of parents and students concerning the quality of undergraduate education are well-founded. Universities should reemphasize teaching in all its aspects, both inside and outside the classroom. In doing so, many institutions will have to curtail some of their research activities. However, if institutions are selective in allocating their resources, the net output of leading-edge research by our nationwide array of research-intensive universities need not decrease.

PCAST recommends that universities strengthen their educational functions by:

- increasing direct senior faculty involvement in teaching at both the undergraduate and graduate levels, and in counseling of students;

- balancing the contributions of teaching and interaction with students with those of research and public service in evaluating and rewarding faculty;

- placing less reliance on graduate teaching assistants and ensuring that they understand their subjects, are better prepared with regard to teaching methods, are able to express themselves well in English, and, like all faculty, are able to provide a supportive environment for women and minority students;

- increasing the involvement of undergraduates in hands-on frontier research; and

- placing greater stress on educating scientists and engineers in key foreign languages.

Even as universities reemphasize teaching, they and their patrons working together must keep tuition and educational costs from rising faster than the income of the average American family.

The federal agencies should ensure that their programs encourage universities to reemphasize education rather than discourage them — even inadvertently — from taking the measures recommended above.

III. A Matter of Public Trust: Restoring Confidence in Our Universities

Public trust in universities is eroding. There is public concern about the rising cost of higher education and about whether the value of higher education is commensurate with the costs. There is also concern about a possible decline in quality, especially in teaching. Both the public and the university community have been shaken by a few, widely publicized cases of scientific misconduct, conflicts of interest, and misuse of federal research funds.

In addition, expectations of what universities can do for the nation are rising faster than are the resources available to meet those expectations. In a time of great change, there is imperfect consensus at best — both locally and at a national level — about where universities should place their emphases. Before issues of resources and priorities can be fully addressed, public trust and confidence in universities must be restored.

In our view:

> the university community and its patrons, including federal agencies, must act in ways designed to preserve the core values that underlie the scientific and educational enterprise — free and creative pursuit of ideas and synergism between research and teaching. Current "politically correct" approaches in some universities are attacking the very foundations of higher education.

In addition to reemphasizing education (see Section II), we urge colleges and universities to:

- establish effective measures to eliminate fabrication, falsification, and plagiarism in scholarly work, and to eliminate fraud and waste in the administration of that work.

PCAST cautions, however, that excessive efforts to anticipate and eliminate all potential problems can lead to bureaucratic strictures that undermine or stifle scientific creativity.

Thomas Murrin and Allan Bromley discussing issues at a PCAST public meeting.

IV. A Matter of Wise Investments: Federal Support of University-Based Research

Short-term constraints on research and development (R&D) resources as well as the likelihood that resources will be limited well into the future have fueled a healthy national debate over priority setting in all sectors. The debate has covered many issues and generated many options. In the context of this report, PCAST addresses only those issues most germane to the relationship between research-intensive universities and the federal government and only those issues directly pertinent to mathematics, the sciences (including the social sciences), and engineering.

PCAST urges, first of all, that the following principles guide the relationship:

- Our nation must continue to invest enough in basic research to sustain world class accomplishments in all major areas of science and technology. In those areas where U.S. activity does not define the frontiers, it must be sufficiently close to those frontiers that we can exploit discoveries without delay, wherever and whenever they are made;

- A healthy federal government-university partnership — particularly in basic research — must be maintained. It has served the nation well since World War II and we have every reason to believe that it will do so in the future;

- Federal agencies must, in their interactions with universities at all levels, recognize that they are investing in institutions that simultaneously generate new knowledge and new talent, and that they are not just procuring research results;

- The federal government must pay the full costs of the university-based research it supports. To expect cost-sharing (except where it strengthens the research-teaching linkage or in other special circumstances) defeats the investment objective and may shift costs to students and their families;

- Federal funds for research should be allocated through competition on a merit basis. Basic research proposals from federal laboratories should compete with those from universities for federal funds. The growing practice of Congressional earmarking of R&D projects and facilities without merit review must cease and must not be initiated or encouraged by universities; and

- Much more attention should be focused on developing criteria for federal and other investments that this nation accepts as appropriate to its long-term goals and aspirations. Criteria, by their nature, have much greater stability and longevity than do priorities, which are extremely sensitive to changes in the environment in which they are made.

In the body of the report, PCAST makes specific recommendations to federal agencies based on the above principles. They address: full federal reimbursement of all legitimate indirect costs; the growing obsolescence of the physical infrastructure for university-based research; improvements in the administration of federal research support to universities; and reexamination of the role of federal laboratories.

The recommendations regarding infrastructure include establishing a substantial federal program for the repair and renovation of university research facilities. The program would be nationally competitive and merit reviewed and would require 50-50 matching from non-federal funds. Support would be available only to institutions that pledged to forego any federal funds earmarked without merit review. The program would operate only for a catch-up period of a few years to enable universities to bring their facilities up to an appropriate level of modernity. Beyond that period, universities would be expected to keep their facilities current on the basis of federal indirect cost support and other resources.

V. A Matter of Two Cultures: Universities and Industry

Some of the cultural differences that have long surrounded industrial research and university research have had the unfortunate effect of unnecessarily inhibiting the most effective interaction between industry and universities. The notion that each sector had its own well-delineated and isolated role and that new knowledge would flow as rapidly as necessary and in one direction from the universities to industry is completely at odds with today's world.

Today the pressure of international competition has introduced a critical time dimension into the system. The issue is not simply how much new knowledge is being generated but also how fast it is being translated into economically and socially beneficial products and processes. This argues for a much greater flow of information and, especially, of people in both directions between universities and industry.

Despite recent gains in building linkages between U.S. universities and industry, there are still too many individuals in each sector who hold negative perspectives, attitudes, and stereotypes with respect to the other sector. The nation cannot afford to have this situation persist, and much more effort is required to overcome it. Even fundamental research that is not expected to yield short-term answers to industry's scientific problems can benefit from being informed by the technical concerns of industry. Conversely, U.S. industry should have the benefit of easy and immediate access to the new knowledge and new talent generated by universities. Exchange of personnel, at all levels, is the surest answer to these problems.

Accordingly, PCAST recommends that:

- universities and industry together, through a wide range of concerted actions, should exchange scientists and engineers at all levels — especially their very best — between the two sectors for substantial periods of time and repeatedly throughout their careers.

VI. A Matter of the Best Scientific Talent: Tapping the Nation's Talent Base

Most important scientific discoveries have been made by a small number of very gifted people who had been provided the opportunity and time to pursue their intellectual interests. Brilliant young people can be found throughout the population — within both genders and every race and ethnic group, in every economic situation, and in every region of the country. Stronger public policies must be designed to identify scientifically-gifted persons at an early age and to help them develop their talents to the fullest, no matter what their circumstances.

If the United States is to continue to lead the world in basic scientific discoveries and in their exploitation, we will need to identify the most talented young people at the earliest possible time, encouraging their interest in advanced education and science, and giving them a sense of purpose as they pursue their education and career paths.

Considering that potential science and engineering talent is well distributed throughout the population, in diverse economic circumstances, and throughout the country, PCAST recommends:

- that the federal government develop programs to award a substantial number of portable undergraduate scholarships and graduate fellowships in science and engineering in each Congressional district. These awards would be made on a nationally competitive basis, using non-political, merit criteria.

As with the traditional program of National Science Foundation graduate fellowships, only citizens and permanent residents would be eligible; awardees would be able to attend any U.S. institution of their own choosing; and reasonable allowances would be included to cover institutional costs. The undergraduate program would include both beginning students and some who have completed one or two years of undergraduate work.

PCAST notes that federal, state, and local tax policies should bolster, not undermine, the nation's investments — both public and private — in human capital. PCAST recommends that:

- federal, state, and local government end all taxation of scholarships, fellowships, and student stipends for participation in research.

Finally, research-intensive universities can have a major effect on the development of scientific talent by educating inspiring teachers of precollege science and mathematics. PCAST, therefore, recommends that:

- research-intensive universities give greater emphasis to the education (including continuing education) of precollege teachers of science and mathematics; and

- the federal government provide scholarships or service-repayable loans to encourage talented students to attend research-intensive universities for careers as precollege teachers of science and mathematics.

BEYOND THE HORIZON

This report is intended to address pressing problems that threaten the productive relationship between the federal government and research-intensive universities. We believe that the fundamental premises of this relationship are sound but that improvements are required for it to avoid deterioration and achieve its fullest potential.

We recognize the present time as one of tumultuous and profound changes in American society and in the world. The ending of the Cold War, the emergence of the European Community and nations of the Western Pacific Rim as economic powers, the changing demography of the American population, the ever increasing power of science and technology, and the growing awareness of new societal problems to which science and technology can be applied all require fresh and creative thinking of overall federal science and technology policy of which federal government-university relations are a part. While the current framework has served us well for four decades, it is far from obvious, as we move into the swifter current of the twenty-first century, that it will retain the validity it had when it was established in the middle of the twentieth century.

In our view, we must look beyond the immediate issues addressed in this report and conduct a broad national reexamination of the place of research and development in our national life — including its fundamental rationale, goals, organization, funding, and administrative mechanisms. The importance of generating new knowledge and new technologies and of educating scientists, engineers, and the general public for the twenty-first century demands no less. It is the intention of PCAST, drawing fully on federal and state government as well as private sector expertise and experience, to undertake such a reexamination in a subsequent report.

RENEWING THE PROMISE: RESEARCH-INTENSIVE UNIVERSITIES AND THE NATION

Progress in the war against disease depends upon a flow of new scientific knowledge. New products, new industries, and more jobs require continuous additions to knowledge of the laws of nature, and the application of that knowledge to practical purposes. Similarly, our defense against aggression demands new knowledge so that we can develop new and improved weapons. This essential, new knowledge can be obtained only through basic scientific research.

Vannevar Bush
Science—The Endless Frontier

THE PROMISE

With these words Vannevar Bush began his momentous 1945 report to President Truman on the role of science and technology in the postwar era. His message was straightforward: without scientific progress and advanced education, the nation could not hope for rapid increases in its standard of living, its economic well-being, the health of its citizens, and its national security.

Science—The Endless Frontier effectively promised the nation that science could yield enormous benefits if three conditions were met:

- That the United States, as a nation, make a substantial commitment to conducting basic research;

- That America's colleges and universities, both public and private, take on the responsibility of providing the nation with the requisite new knowledge and scientific and engineering talent;

- And that the federal government provide the funds to enable academic institutions to meet those new responsibilities.

Out of those conditions emerged a unique partnership between the federal government and America's colleges and universities. The public would invest in institutions of advanced learning and scholarship, and those institutions would in turn produce the new knowledge, understanding, and human capital that would fuel economic growth, improve public health, and strengthen national security.

What is a Research-Intensive University ?

No other nation has the advantage of such a large and diverse collection of world-class universities, each of which has developed strong capabilities in many fields of basic research, advanced education and public service. How many can be called "research-intensive" depends on the criteria applied — such as number of graduate students, national and international reputation, size of faculty, size and significance of their research and education programs, or amount of Federal research funding.

For purposes of this report, the precise number is not important. However, PCAST was curious as to what overall number of universities performed most of the research and educated most of the doctoral students. Using two criteria — namely, those that together produced 90% of the Nation's doctorates in science and engineering between 1981 and 1990 (the latest available year), and expended 90% of academic research and development funds from all sources during that decade — resulted in a total of 170 universities.

These universities are located in virtually every state. Some states with large populations, such as California, New York, Texas and Massachusetts, have several; others such as Michigan, Florida, Illinois and Wisconsin, have fewer but generally larger ones. About two-thirds are state institutions, and the rest privately-governed. Significant increases in state and federal funding for education and research during the 1960s, and again in the 1980s, led to the creation or expansion of many state universities — particularly as Southern and Western states grew in population.

The character of each research-intensive university depends on its individual history. They range, for example, from the large land-grant universities of the Midwest — with their teaching hospitals, agricultural extension services and sizable engineering schools — to mid-size institutions founded by religious organizations long before the Revolution, to smaller polytechnical universities that concentrate in a few fields. And beyond any total that could be generated using broad criteria, there are many other universities with one or several nationally-competitive research departments, developed in response to local or regional industry needs or some other feature unique to the institution's location.

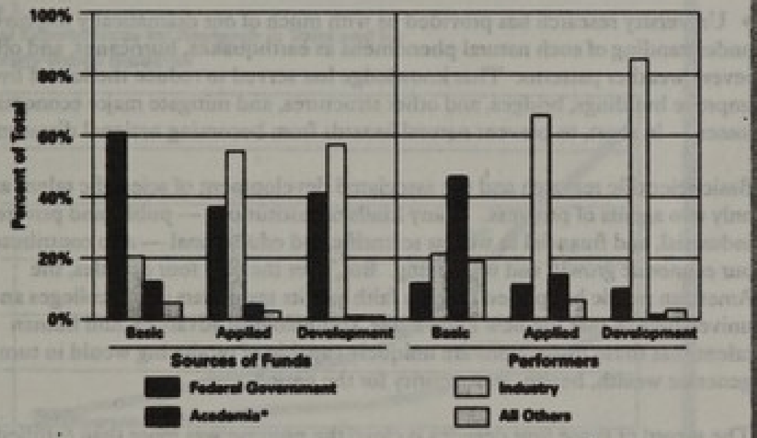
The Promise Fulfilled

Vannevar Bush's vision ultimately led to the establishment of the largest and strongest scientific and higher education enterprise that the world has ever seen. This enterprise has fulfilled the promise of science to a greater extent than could possibly have been anticipated right after World War II. To cite a few of the most dramatic examples:

- Agricultural research conducted at our land-grant and other universities has served as one of the earliest models of a federal government-university partnership. The continuation of that partnership since World War II has led to productivity levels so great that two percent of the population of the United States produces enough food for our entire nation and large surpluses for export as well;

- Research in medicine and the biological sciences carried out in our universities and medical schools has led to vast improvements in the health of people around the world and has generated a new biotechnology industry in the United States;

Figure 1
Distribution of National R&D Funding by Source, Performer, and Character of Work, 1991



* For performers, includes university Federally Funded Research and Development Centers (FFRDCs)

Source: National Science Foundation

Diversity is a prominent characteristic of the U.S. R&D system. In no other nation do so many different sponsors foster discovery and innovation in so many different disciplines within so many different institutions. Yet, amidst this diversity, basic research is significantly dependent upon a single class of relationships — those where a federal agency is the sponsor and a university is the performer. During 1991, of the $23.5 billion expended within the United States for basic research (16 percent of all R&D expenditures that year), the federal government provided over 60 percent of the funds, while universities carried out almost half (47 percent) of the work.

- University research on the structure of matter and the properties of materials provided the key foundations for a multibillion-dollar microelectronics industry, which in turn has fueled computer and telecommunication industries and has changed the nature of society throughout the world;

- Basic materials research has also led to critical advances in aerospace and other technologies. These, together with electronic and computer technologies, have been among the resources with which the United States buttressed its national security during more than four decades of the Cold War;

- Social scientists at our universities have provided us with the fundamental concepts that underlie the survey research and economic analyses on which business institutions rely for their marketing and financial planning and on which federal, state, and local governments depend in making public policy;

- Many technologies flowing from fundamental university research have made possible a whole new era of entertainment, continuing education, and public information access;

- Fundamental advances in physics, chemistry, and biotechnology have spawned a revolution in environmental science and technology. For example, rather than simply dispose of hazardous wastes, the focus is now on reduction of waste at the source and on reclaiming valuable components of industrial and other waste streams to yield environmentally benign residues; and

- University research has provided us with much of our dramatically improved understanding of such natural phenomena as earthquakes, hurricanes, and other severe weather patterns. That knowledge has served to reduce the loss of lives, improve buildings, bridges, and other structures, and mitigate major economic losses — in short, to prevent natural hazards from becoming national disasters.

Basic scientific research and the associated development of scientific talent are only two agents of progress. Many kinds of institutions — public and private, industrial, and financial as well as scientific and educational — also contribute to our economic growth and well-being. But, over the past four decades, the American public has placed both its faith and its tax dollars in our colleges and universities so that the new knowledge, technological advances, and human talent that these institutions are uniquely capable of producing would in turn generate wealth, health, and security for the nation.

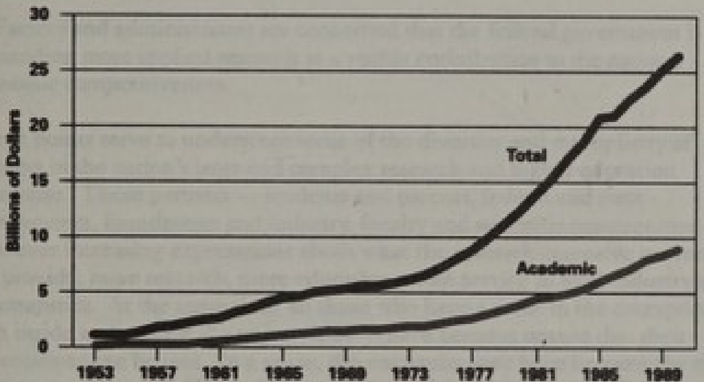
The record of those four decades is clear: the promise was more than fulfilled, the faith of the public was rewarded, and the investment continues to pay off.

THE GROWTH OF THE ENTERPRISE

The federal research enterprise in America has become large and very complex, involving more than twenty federal agencies, each with its own mission, managing hundreds of individual programs. More than one hundred and fifty universities are at the center of that enterprise. Because most faculty at those institutions devote considerable efforts and resources to research as well as teaching, the universities are referred to in this report as "research-intensive universities." They are dispersed over virtually every state in the Union and exhibit considerable diversity in size, character, and governance. The interrelationships between the federal government and those universities loom large for both partners, although this is but one component of a complex array of university activities and federal research programs.

Federal support of university- and college-based programs has grown substantially since World War II. This support has focused on student aid and the sponsorship of research activities, particularly basic research. Overall, the U.S. system of research-intensive universities is roughly three times the size it was thirty years ago: in enrollment and degree production at all levels, in numbers of faculty, and in numbers of research staff. The capacity of our universities to produce doctorates is well over ten times what it was in the immediate postwar years.

Figure 2
Federal Expenditures for Research in Total and for University-Based Research



Source: National Science Foundation

The federal government has been and continues to be the principal source of funding for the substantial expansion of U.S. research activities that has been underway since the end of World War II and especially since the mid-1970s. Federal funding for university-based research has constituted a significant fraction of this investment throughout the last four decades, reaching approximately $9 billion or almost 35 percent of the total in 1990.

In real (inflation-adjusted) terms, federal support for university-based research is now about five times what it was thirty years ago. Although federal support is still concentrated in a relatively small number of institutions, over three decades more institutions have become larger partners in federally supported research and development (R&D). In the postwar period scarcely a dozen institutions received half the federal funds granted to universities. At present, over thirty universities account for that fifty percent share.

In sum, the implementation of Vannevar Bush's 1945 vision has led to the unprecedented growth of research-intensive universities throughout the nation.

Signs of Stress

The strength of the enterprise and the great value of its contributions to the nation notwithstanding, the relationship between the American public and institutions of higher learning is showing serious signs of stress. In the current public debate on research and education in American universities and colleges, the following points are frequently heard:

- Students and their families are concerned that the quality and value of the education provided by colleges and universities are not commensurate with its rising cost;

- Faculty and administrators express deep concern that, despite a steady and substantial growth of government support, resources for basic research and advanced training are falling far short of what is required either to permit exploitation of the myriad opportunities that have been opened up through research successes in recent decades or to enable our growing national pool of highly trained investigators to pursue their scientific careers;

- Both the university world and the tax-paying public have been disturbed by isolated but sobering incidents of faculty and institutional misconduct. This has diminished the nation's confidence in academic institutions;

- Various members of the higher education community have described the relationship of their institution to the federal government, particularly as it pertains to the support of university-based research, as increasingly adversarial; and

- Faculty and administrators are concerned that the federal government is demanding more applied research as a visible contribution to the nation's economic competitiveness.

These points serve to underscore some of the diversity and multiplicity of partners in the nation's large and complex research and higher education enterprise. Those partners — students and parents, federal and state governments, foundations and industry, faculty and scientific communities — have ever increasing expectations about what the research-intensive universities can provide: more research, more education, more service to local industry and communities. At the same time, all those who have a stake in the enterprise — both inside and outside the universities — have become unsure that their expectations can be met. In a sense, the enterprise may have become the victim of its own success. As Hanna Gray, president of the University of Chicago, suggested in her 1992 keynote address to the American Association for the Advancement of Science,

> *Our universities have arrived at a stage of maturity burdened by too many tasks . . . and too great a confusion of expectations, by the consequences and distortions of excessive growth, . . . and by the illusion that comprehensiveness is necessary for institutional distinction.*

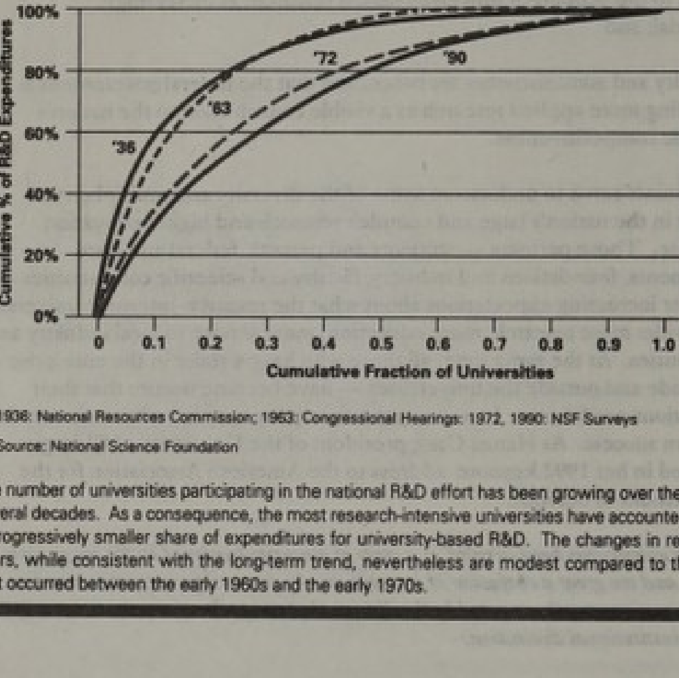
VARIOUS MEMBERS OF THE HIGHER EDUCATION COMMUNITY HAVE DESCRIBED THE RELATIONSHIP OF THEIR INSTITUTION TO THE FEDERAL GOVERNMENT . . . AS INCREASINGLY ADVERSARIAL.

Ever Increasing Expectations

World War II left the United States in a position of economic preeminence with respect to both its defeated adversaries and its devastated allies. It also left us in a newly adversarial position with respect to the Soviet Union, the central and eastern European nations that the USSR had come to dominate, and its then ally, China. Much of the rest of the world was emerging from a long colonial era. The national security imperatives of the Cold War — particularly the aerospace and electronic requirements of defense — were one of the engines that drove much of the federal government's commitments to R&D for four decades. Other important engines have been commitments in the area of health and the needs for an assured energy supply and for a more highly trained labor force.

With the remarkably swift end of the Cold War and major political shifts in the world, the long-term national security needs of the United States cannot be easily defined today. What is likely is that uncertainty will become a feature of a more fluid international system. Preparedness in the face of uncertainty is even more complex and ultimately more technologically demanding. If anything, technological advances will be more important than ever before in ensuring our national security needs.

Figure 3
Increasing Dispersion of the Nation's University-Based R&D Activity as Shown by Expenditure Distribution in Four Selected Years



1936: National Resources Commission; 1963: Congressional Hearings: 1972, 1990: NSF Surveys

Source: National Science Foundation

The number of universities participating in the national R&D effort has been growing over the last several decades. As a consequence, the most research-intensive universities have accounted for a progressively smaller share of expenditures for university-based R&D. The changes in recent years, while consistent with the long-term trend, nevertheless are modest compared to those that occurred between the early 1960s and the early 1970s.

Although the Cold War, with its complex set of implications for the nation's R&D programs, is no longer center stage, new developments, particularly in the international economy, are presenting new challenges for the nation. The industrial economies of Japan and Germany as well as those of major Western European countries have been rebuilt, largely on the basis of technology-intensive strategies. Former colonial and quasi-colonial economies on the Pacific Rim — South Korea, Taiwan, Hong Kong, and Singapore — have surged ahead with export-led strategies rooted principally in the electronics industry. All of these countries, as well as others — such as China — on the horizon, will continue to pose a powerful economic and scientific challenge to the United States.

PCAST IS CONCERNED THAT AMERICA'S UNIVERSITIES ARE NOT AS WELL POISED AS THEY SHOULD BE TO ASSUME THE RESPONSIBILITIES OF THE FUTURE.

Paralleling the widespread economic and population growth of the past three decades has been the emergence of global environmental concerns. By their very nature these can only be addressed on a multinational basis — both in terms of a scientific understanding of complex physical, biological, and human phenomena and in terms of policy responses to environmental threats. This is another of the new R&D challenges before us. Finally, we are approaching a new frontier in the area of the life sciences that provides many new opportunities for both the relief of human suffering, the further advancement of world agriculture, and the development of important new industries.

As America looks to the future, it is clear that the nation's dependence on its colleges and universities for creating new knowledge and training new talent will be greater than at any time in our history. Over more than four decades our research-intensive universities have shouldered a weighty responsibility for the nation. Reflecting a unique American belief that higher education and research are inextricably linked and synergistic, we have made equally unique demands on our research-intensive universities — both for new knowledge and for young minds trained to use it in a creative and innovative fashion. No other nation has made comparable demands on their universities.

PCAST is concerned that America's universities are not as well poised as they should be to assume the responsibilities of the future. PCAST is also concerned that the American public no longer has the confidence in universities that they will need if they are to meet those responsibilities. This unhealthy situation puts the nation's future in jeopardy.

PCAST has sought to identify the weak points that threaten the otherwise strong web that has bound together for many decades the federal government and the tax-paying public with the research-intensive universities. In the six sections that follow, PCAST presents its findings and recommendations for restoring the relationship.

I. A Matter of Limits: Adapting to a New Resource Environment

"We are in the paradoxical situation of being unable to support adequately all of the valuable scientific work we are now capable of doing, while at the same time we are generating the capacity to do more."

Robert M. Rosenzweig, President, Association of American Universities
July 1992 statement to PCAST

"America's research universities today rest on unstable and shifting ground."

Charles Vest, President, Massachusetts Institute of Technology
June 1992 statement to PCAST

ADVANCING THE FRONTIERS OF KNOWLEDGE IS NOT, AS IT ONCE MAY HAVE BEEN, A MATTER OF INTELLECTUAL LUXURY. IN AN ERA OF RELENTLESS GLOBAL ECONOMIC COMPETITION, IT IS A NATIONAL IMPERATIVE.

Advancing the frontiers of knowledge is not, as it once may have been, a matter of intellectual luxury. In an era of relentless global economic competition, it is a national imperative. The United States must continue, as a nation, to invest in fundamental research. Because the ultimate applications that might derive from fundamental research are largely unforeseen, there are no easy answers to such questions as "how much basic research is optimal?" or "in what specific areas of science should investments be concentrated?" Expenditures in basic research are an investment with returns that, although unknowable in advance, have proved enormous in the past and are likely to be even greater in the future.

A realistic assessment of the challenges facing America in the next decades indicates that the key issues before us will be different from those of the past. In particular, unless we achieve more robust and sustained levels of economic growth we will face some very difficult choices. In such an environment, all public resource commitments will receive new levels of scrutiny, and the university-based system of research and education is not likely to expand for the indefinite future. It is probably unreasonable to expect that the system will continue to grow as it did for periods in the 1960s and 1980s. Given the resources that the nation is willing and/or able to devote to this enterprise, the system may already have exceeded its steady state capacity.

The financial stresses already experienced by both our institutions of higher learning and their many different supporters — students and their families, the federal government, and state and local governments — are only in part a reflection of ongoing economic cycles. These short-term conditions should not obscure longer-term challenges brought about by relatively slow growth in family income, intense international competition, and rising costs of cutting-edge education and research.

Quite apart from particular economic conditions, the nation has to contend with two sets of cost issues. The first is that the system contains two built-in growth factors. Almost all research breakthroughs open multiple opportunities that can be pursued, each holding the promise of new technologies, new industries, new conquests over disease, and new tools for improving the human condition. These developments raise national productivity, wage rates, and the cost of attracting talented investigators to the research enterprise. Furthermore, the system has a kind of "natural population growth." Each university scientist usually trains many new scientists, several of whom now typically remain in the university system.

The second cost issue pertains to inflation — not only that which affects the economy as a whole, but "sophistication inflation." Each scientific advance requires more complex and sophisticated techniques, instrumentation, and facilities than did the last. Each successive step forward is a longer step but a more costly one as well.

IT IS PROBABLY UNREASONABLE TO EXPECT THAT THE SYSTEM WILL CONTINUE TO GROW AS IT DID IN THE 1960S AND 1980S.

The cross-pressure of expanding opportunities for investment in research and constrained resources poses a risk for the United States: spreading our resources too thinly across an array of highly trained investigators and research-intensive universities. The relentless quest for an ever broader range of activities will inevitably destroy the most important aspect of American higher education and research — quality. We cannot afford to allow higher education to decline to the levels of mediocrity that now characterize much of our precollege education.

Most of our research-intensive universities aspire to excel in all or most areas of scholarship and education. As worthy as those aspirations might seem, they are likely to be ill-advised. They cannot be fully realized in an era of relatively constrained resources. Our research-intensive universities must adopt more highly selective strategies.

Even for those who still believe in optimistic scenarios, an important observation applies. Those institutions that have maintained the highest standards of quality by being selective in their investments in faculty and physical plant are the ones that will be in the best position to compete successfully for and make effective use of any significant new resources that might become available.

Recommendation One: Adapt Quickly and Responsibly to a Constrained Resource Environment

So that research-intensive universities may continue to function productively in an environment of limited resources, PCAST urges them to:

> adopt more highly selective strategies based on a realistic appraisal of the future availability of resources and a commitment to meet world class standards in all programs that are undertaken.

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Such strategies will require universities to:

- eliminate or downsize some departments and specialties within departments rather than sustain less than world-class activities in every area of science and engineering;

- collaborate with nearby institutions (academic, industrial, and governmental) in sharing instructional and research facilities and programs, with the aim of conserving limited resources;

- build facilities or programs only where there are strong long-term prospects of sustaining them. The expectation that, somehow, new resources will become available to sustain initiatives must be viewed with skepticism. Without long-term sustainability, initial investments result in squandered resources; and

- develop permanent institutional mechanisms for strategic planning that will foster a balance between activities and resources and among teaching, research, and other missions that are commensurate with society's values and the needs of the universities.

SPREADING OUR RESOURCES TOO THINLY . . . WILL INEVITABLY DESTROY THE MOST IMPORTANT ASPECT OF AMERICAN HIGHER EDUCATION AND RESEARCH — QUALITY.

PCAST also urges federal agencies and other supporters of research-intensive universities to:

- refrain from encouraging universities to embark on new research, new education programs, or the building of facilities when there is little or no long-term prospect of sustaining them; and

- refrain from developing or implementing research or education programs that would increase the net capacity of the nation's research-intensive universities.

II. A MATTER OF EDUCATION: THE IMPORTANCE OF TEACHING AT OUR UNIVERSITIES

Conducting research has become such an overwhelming focus on today's campuses that those professors who still manage to teach more than a few hours a week are actually looked down upon by their peers, to say nothing of the negative effect teaching has on chances for tenure, pay and promotion.

Representative Patricia Schroeder
Chairman, Select Committee on Children, Youth and Families

The best teacher in the world is known only to the perimeter of his campus, while a mediocre researcher is known around the world.

Norman Hackerman, former president of
the University of Texas at Austin and of Rice University and
former Chairman of the National Science Board

To meet a wide range of its future needs, the Nation will have to educate a higher percentage of its citizens in science and technology. Those needs include:

- filling demanding positions in competitive, high-technology manufacturing industries such as computers, biotechnology, and medical instrumentation;

- finding solutions to a wide range of problems in such areas as environmental control and disease prevention;

- making sound decisions in technically-based spheres of corporate management, legal affairs, and public policy; and

- participating effectively as citizens of a democratic society, by having the ability to understand the principles of technologically-oriented public policy issues.

But at the very time that highly-trained scientists, engineers, and technicians and scientifically literate lay persons are more important than ever to our society, declining numbers of high school students are interested in science and technology, and most have inadequate precollege preparation in these areas.

In addition, the traditional model for producing scientists and engineers — where one completed a formal college or graduate school education and then moved on to career activities having completed education — if it was ever true, is no longer valid. If the system does not adapt to massive changes in the demographic composition of the student body (which is older on the average, culturally and ethnically more diverse, and includes many individuals attending college part-time) and does not take advantage of relatively new post-secondary institutions such as community colleges, opportunities may be foreclosed to some talented

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The U.S. Higher Education System

Higher education is a major, complex and diverse enterprise in the United States. Overall, it comprises more than 3,000 colleges, universities, specialized institutions and professional schools, employing a total of 750,000 faculty and serving about 12.4 million students.

Several types of institutions play varying roles in educating students for mathematics, science, medicine and engineering. Many of the 1,250 two-year colleges have important missions in technician training, especially to meet the needs of local industry — and a sizable and expanding role in preparing students for transfer to baccalaureate institutions. There are about 1,270 institutions with programs primarily at the bachelors'- and masters'-degree levels. They annually award about 180,000, or 55%, of the baccalaureates, and about 40% of the 60,000 masters' degrees, in science and engineering.

Another way of viewing higher education institutions is by the student populations they serve. More than a hundred historically black colleges and universities, some of considerable distinction in research, education and medicine, have evolved from segregationist beginnings in Southern states. Also, as the demography of the U.S. population changes, a growing number of colleges and universities in several areas of the country now have student bodies comprising sizable numbers of Hispanic-Americans and Asian-Americans.

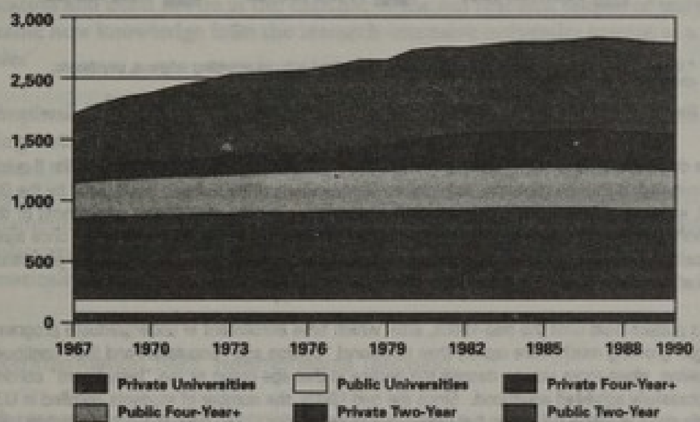
Faculty at those institutions and at hundreds of others contribute to the Nation's research effort; about 1,100 colleges and universities annually report at least some spending on research. A small group of highly selective liberal arts colleges send a relatively larger proportion of their students on to the doctorate than do most four-year institutions; indeed, faculty at these "research colleges" regularly win nationally-competitive funding for their own research.

In fields other than science and engineering, almost all four-year degree holders have completed two or more science courses and two or more mathematics courses. Many of them will become pre-college science or mathematics teachers, and many others will become leaders in business or government who make decisions involving scientific or technological matters. And most are (or become) citizens who will exercise many choices during their lifetimes about public issues having substantial scientific or technical content.

persons not on the traditional path. Education must be viewed as a continuing, life-long component of the life of each of our citizens, and an attractive, accessible means of achieving life-long education must be provided throughout the nation.

Improved teaching and learning of science and technology are needed throughout the system. All institutional levels — elementary schools, junior high schools and high schools, two-year colleges, undergraduate colleges and universities, and doctoral institutions and those involved in continuing education — have a role and a stake in providing a high-quality education in science and technology to all of their students. Research-intensive universities have a particularly powerful role as a consequence of their extensive research programs and associated activities with industry and government and their responsibilities in preparing the next generation of teachers.

Figure 4
Number of Academic Institutions by Type

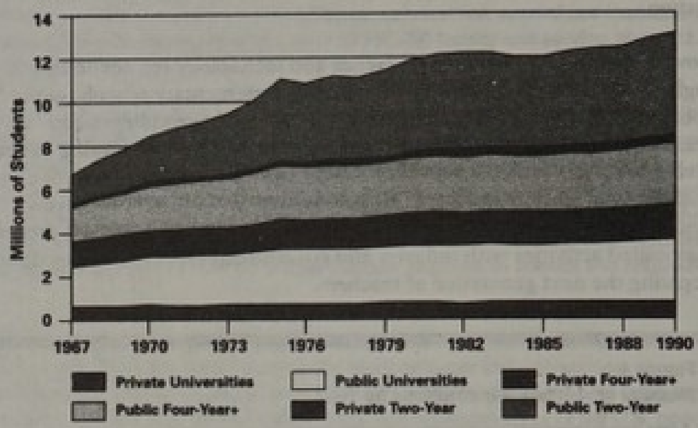


Source: National Science Foundation and Department of Education

The U.S. system of higher education could not possibly have kept pace with the enrollment increases without significant structural change; and that change was well underway by the mid-1960s. The most prominent feature was the creation of about 1,000 new two-year colleges. The continuing challenge with respect to science and technology is to help ensure that these colleges provide the educational opportunities — both directly and through affiliations with four-year colleges and universities — that will prepare students for science and technology careers.

"Universities" refers to institutions typed by the Carnegie Foundation for the Advancement of Teaching as "research" and "doctoral". "Four-year+" refers to Carnegie's "comprehensive" and "liberal arts" institutions.

Figure 5
Higher Education Enrollment* by Type of Institution



* Includes part-time students. Excludes highly specialized schools providing religious, psychiatric, chiropractic, etc. training.

Sources: National Science Foundation and Department of Education

The decline in college and university enrollments that inevitably accompanied World War II quickly reversed during the post-War years as former members of the military, many aided by the G.I. Bill, entered or reentered higher education. However, by the mid-1950s, when most of the cohort of returning veterans had passed through the system, the level of enrollment once again became primarily a function of the number of traditional "college age" persons in the population — i.e., the 18-21 year-olds.

This pattern held until the mid-1960s, after which time enrollment in undergraduate programs began growing much more rapidly than traditional "college age" population and then continued growing, albeit more slowly, despite the decline in that age group as the "baby boom" cohorts successfully achieved adulthood. Since the mid-1960s, the number of students enrolled in U.S. institutions of higher education has grown by a factor of four — i.e., from about 3.5 million in 1960 to about 13 million in 1990. This was the result of increasing participation of many different age groups, especially students over 25 years of age, as well as women and minorities in general.

However, many higher education institutions, including research-intensive universities, have come under fire for seeming to turn away from education, especially of undergraduates, toward research and other activities. Parents and students complain of:

- too little direct contact between undergraduate students and senior faculty, both in and outside of the classroom;

- too much reliance on persons other than faculty members for educational counseling;

- too many early courses taught by graduate teaching assistants — some of whom are ill-prepared to teach, some not fluent in English, and some exhibiting hostile attitudes toward women and minority students;

- too many course offerings, including some that appear duplicative or that reflect very narrow faculty interests peripheral to students' needs for an intellectually integrated education;

- years of continuing tuition increases, severely pressuring a family's capability to afford higher education — particularly given recent economic conditions; and

- failure to orient students to the full range of intellectual and career possibilities of the world into which they will graduate.

America's educational needs are greater than ever. It is critical to the nation's future that universities reemphasize their educational mission and apply their unique resources to society's educational requirements. PCAST believes that increased attention to educational activities need not drive up the costs of education and need not be at the expense of the net research output of truly valuable new knowledge from the research-intensive university system as a whole.

Reemphasizing education will require improving teaching performance and raising teaching productivity, as difficult as those may be to evaluate and measure. While experience has demonstrated clearly that prior research performance is the best available indicator of future professional productivity, it is fundamentally more difficult to measure teaching performance. For example, evaluations of teachers by students five years after graduation are typically dramatically different from evaluations made at the time courses are taken.

Recommendation Two: Reemphasize Teaching

Each research-intensive university should review, in a searching and comprehensive manner, the nature and quality of its teaching programs — particularly in science, mathematics, and engineering — with a view to improving teaching performance and productivity. PCAST in no way implies that performance and productivity problems are limited to those fields; rather our experience and expertise limit our consideration to them. More specifically, each research-intensive university should develop policies and programs to:

- increase direct senior faculty involvement in teaching at both the undergraduate and graduate levels and in counseling of students;

- balance the contributions of teaching and interaction with students with those of research and public service in evaluating and rewarding faculty;

- place less reliance on graduate teaching assistants and ensure that they understand their subjects, are better prepared with regard to teaching methods, are able to express themselves well in English, and, like all faculty, are able to provide a supportive environment for women and minority students;

- increase efforts to involve undergraduates in hands-on frontier research; and

- place greater stress on educating scientists and engineers in key foreign languages.

Even as universities reemphasize teaching, they and their patrons working together must keep tuition and educational costs from rising faster than the income of the average American family.

In addition, the research-intensive universities should:

- develop new pedagogies, including technology-based teaching methods, for undergraduate teaching. These new pedagogies should be aimed as much or more at non-science majors as at those intending to pursue careers in science and technology;

- help two-year institutions improve curriculum quality and develop agreements about transferability of credits;

- where appropriate resources and talents exist, assist with national, state, and local efforts to redesign and revitalize precollege education, especially in science and mathematics; and

- give special attention to undergraduates who intend to become precollege teachers of science and mathematics. These individuals must have a thorough grounding in those topics.

The federal agencies should ensure that their programs encourage universities to reemphasize education rather than discourage them — even inadvertently — from taking the measures recommended above. In particular, federal agencies should:

- provide incentives for outstanding undergraduate and graduate teachers in the fields of science and technology, such as awards and special national recognition for their accomplishments; and

- develop or expand sustainable programs that would assist research-intensive universities in meeting the objectives described above.

III. A Matter of Public Trust: Restoring Confidence in Our Universities

Cutting through all of the "excellence" and "quality" rhetoric reveals one very clear point: the focus in higher education today is on research, not teaching. This fact has not been lost on the professors. If you don't believe me, go ask one yourself. However, don't look for a professor in a classroom; it's unlikely you'll find one.

Representative Patricia Schroeder
Chairman, Select Committee on Children, Youth and Families

"Universities have been over-responsive to those who seem to think that they should carry out every function and address every concern that might be of interest to citizens in general. They need to return to the criterion that measures what they can do, and do well, that other institutions cannot do, or do as well, and stick to their own special purpose, or it will be lost."

Hanna Gray, President of the University of Chicago
Keynote address to the American Association for the Advancement of Science, 1992

Public confidence in universities is eroding. Although studies show that the economic value of an advanced education has increased substantially in the last decade, there is nevertheless a growing concern that tuition and related costs are rising too quickly and that the teaching programs of the research-intensive universities should receive more attention. Students, parents, and legislators are raising concerns that those institutions have shifted their attention too far toward performance of research and away from dedication to students. In the current economic environment, continuing tuition increases leave middle-class parents wondering how they will be able to afford to send their children to an institution of their choice and whether they will receive full value for what they invest.

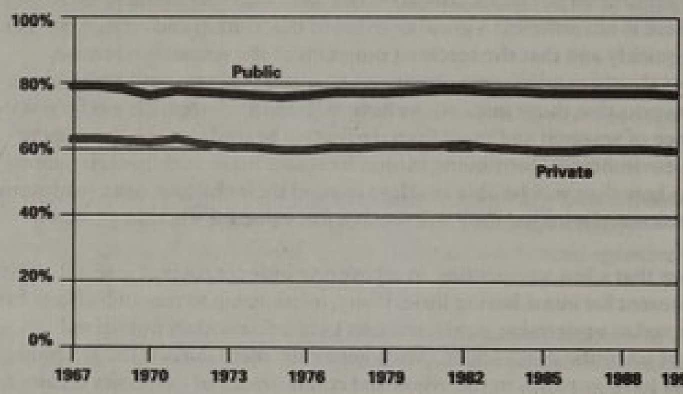
PUBLIC CONFIDENCE IN UNIVERSITIES IS ERODING.

Revelations that a few universities, in recovering indirect costs of research, billed the government for items having little, if any, relationship to research efforts have further served to undermine public trust, as have a few widely publicized instances of scientific misconduct. More generally, some outside the academic community have lost faith in the vision and commitment of university faculty and administrators, in their management of universities, and in their use of the resources currently available to them. Exacerbating these problems have been responses from some of the individuals and institutions involved that were interpreted by the public as arrogant.

The notion of a university as a community of scholars having shared interests in certain critical tasks, such as undergraduate education, is under siege from inside universities themselves. Some members of the academic community — at times spurred by their reassessment of our history and culture — act as if they have lost faith in the continuing vitality of such core values of the scholarly enterprise as free inquiry, tolerance, scholarly integrity, verifiable ways of knowing, and open communication of new ideas. Current "politically correct" activities on many campuses attack the fundamental values and foundations of the modern university. Some faculty pursue their own work without regard for their institution as a whole or for the coherence of its teaching curriculum.

Factors that undermine public trust can be placed in three general categories. Some, such as fabrication of research results and misuse of funds, however isolated in their incidence, are universally acknowledged as grossly inappropriate and illegal. Some, such as banning of "politically incorrect" speakers or teachers, undermine some of the deepest values of academia. And some, such as debates about the balancing of efforts among research, teaching, and community outreach, may reflect important disagreements about priorities of missions and resources.

Figure 6
Undergraduate Enrollment as a Percent of Total Enrollment in Research-Intensive Universities



Source: National Science Foundation

Undergraduate education is a significant function for the research-intensive universities. Bachelors-degree candidates have accounted consistently for about 60 percent of the enrollment in private research-intensive universities and about 80 percent of the enrollment in public research-intensive universities.

Research-intensive universities are very complex institutions with many outputs and many patrons, each of whom tends to expect the output it funds to have the highest priority and to be the most heavily subsidized by others. Students (and their parents) expect a high-quality education, including significant personal contact with the senior faculty that give the institution its reputation. State governments expect state-supported universities to offer a full range of graduate and undergraduate courses, at low tuition, to a large proportion of the state's high school graduates. Local industry and government expect to be able to hire graduates that are ready to work in their companies and agencies. Universities with medical schools and teaching hospitals are expected to offer high-quality, affordable health care to the public. Agricultural and forestry interests depend heavily on university extension services. Companies, foundations, and government agencies that help fund research expect top-rank work, well-educated graduates, and, increasingly, efforts to ensure that research results are used to generate industrial advances and jobs.

Having many missions and sponsors tends to pull research-intensive universities in several conflicting directions at once. Various sponsors demand that they:

- be both more business-like (e.g., focus on the "bottom line") *and* less business-like (focus on maintaining ideals and not "merely" on the bottom line);

- do both more scientific research (e.g., to help with economic competitiveness) *and* less research (e.g., more teaching and public service);

- both increase quality and quantity of services *and* cut costs; and

- be both the guardians *and* the critics of our cultural inheritance.

Each institution has to confront its unique set of conflicting demands originating with its unique set of constituencies. Whatever its approach, however, each institution must focus on the fundamental issue of public trust and confidence. Without those and the ensuing public support, our nation's research-intensive universities will not be able to meet the nation's needs.

RESEARCH-INTENSIVE UNIVERSITIES ARE VERY COMPLEX INSTITUTIONS WITH MANY OUTPUTS AND MANY PATRONS, EACH OF WHOM TENDS TO EXPECT THE OUTPUT IT FUNDS TO HAVE THE HIGHEST PRIORITY AND TO BE THE MOST HEAVILY SUBSIDIZED BY OTHERS.

Recommendation Three: Restore Public Trust and Confidence

In our view:

> the university community and its patrons, including federal agencies, must act in ways designed to preserve the core values that underlie the scientific and educational enterprise — free and creative pursuit of ideas and their implications, scholarly rigor, trust in rationality and in verifiable forms of knowledge, and belief in the benefits of the synergism of research and teaching as investments in the nation's future. Intolerance for alternative ideas, or absolute insistence on "politically correct" behavior, represents a kind of dry rot that will, if allowed to remain, undermine the nation's institutions of higher education.

In addition to reemphasizing education (see Section II), we urge colleges and universities to:

- establish effective procedures to eliminate fabrication, falsification, and plagiarism in scholarly work, and to eliminate fraud and waste in the administration of that work.[1]

PCAST cautions, however, that excessive efforts to anticipate and eliminate all potential problems can lead to bureaucratic strictures that undermine or stifle scientific creativity.

[1] A valuable discussion of this subject can be found in the recent report of the Panel on Scientific Responsibility and the Conduct of Research of the Committee on Science, Engineering, and Public Policy, entitled *Responsible Science: Ensuring the Integrity of the Research Process*, Vol.I, National Academy Press, Washington, DC, 1992.

IV. A Matter of Wise Investments: Federal Support of University-Based Research

While watching Michael Faraday at an experiment, British parliamentarian William Gladstone was said to ask 'Of what use is such a discovery?' Faraday is said to have replied: 'Why, sir, you will soon be able to tax it!' A more recent British politician, Margaret Thatcher, recently noted that 'Although basic science can have colossal economic rewards, they are totally unpredictable. And therefore, the rewards cannot be judged by immediate results. Nevertheless, the value of Faraday's work today must be higher than the capitalization of all the shares on the stock exchange.'

recounted by Thomas Everhart,
President of the California Institute of Technology
July 1992 statement to PCAST

Short-term constraints on R&D resources as well as the likelihood that resources will be constrained well into the future have fueled a healthy national debate over priority setting in all sectors. The federal government — both in the Executive Branch agencies and in Congress — state and local governments, universities, industry, scientific associations, and foundations have all debated and searched for the optimal strategies for expending public and private resources on R&D.

The choices to be made are many: within fields of science; among fields of science; between "pure" research that has no obvious immediate application and "strategic" or "thematic" research that has some expectation of yielding short-term practical applications; among basic research, applied research, and development; between "big" science and "small" individual investigator science; between research itself and the facilities and instrumentation required to conduct research; between government laboratories and universities.

None of these choices is easy, and this report will not add one more set to the many contending options already on the table. Rather, we stress a few essential principles:

- Our nation must continue to invest enough in basic research to sustain world class accomplishments in all major areas of science and technology. In those areas where U.S. activity does not define the frontiers, it must be sufficiently close to those frontiers that we can exploit discoveries without delay, wherever and whenever they are made;

- A healthy federal government-university partnership — particularly in basic research — must be maintained as part of the core of a successful U.S. science and technology enterprise. It has served the nation well since World War II and we have every reason to believe that it will do so in the future;

- The federal government must, in its interactions with universities at all levels, recognize that it is investing in institutions that simultaneously generate new

INTOLERANCE FOR ALTERNATIVE IDEAS, OR ABSOLUTE INSISTENCE ON "POLITICALLY CORRECT" BEHAVIOR, REPRESENTS A KIND OF DRY ROT THAT WILL, IF ALLOWED TO REMAIN, UNDERMINE THE NATION'S INSTITUTIONS OF HIGHER EDUCATION.

knowledge and new talent, and not just procuring research results. The knowledge and talent generated may not always directly or immediately benefit a particular government mission, but it constitutes important national capital that will serve many different purposes;

- The federal government must pay the full costs of the university-based research it supports. To expect cost-sharing (except where it strengthens the research-teaching linkages or in other special circumstances) defeats the investment objective and may shift costs to students and their families. The universities, on the other hand, must commit to using all federal funds that support facilities and equipment for the maintenance of those important elements of their research infrastructure;

OUR NATION MUST CONTINUE TO INVEST ENOUGH IN BASIC RESEARCH TO SUSTAIN WORLD CLASS ACCOMPLISHMENTS IN ALL MAJOR AREAS OF SCIENCE AND TECHNOLOGY.

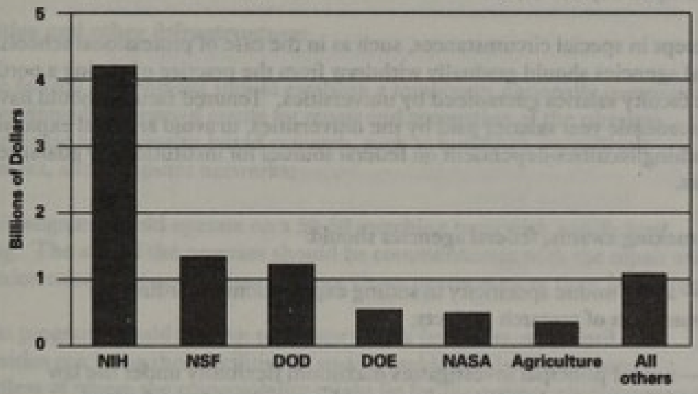
- Federal funds for research should be allocated through competition on a merit basis. There is no better method for ensuring quality and maximizing the dividends of our investment than for proposed research to be subjected to competition based on scientific merit;

  — There are currently two specific areas in which the principle of merit-based competition is not followed. One is in the support of basic research in federal laboratories. Though this research may be reviewed for its technical merit, it is rarely subjected to direct competition with research proposals from other institutions, such as universities. When the primary mission of a laboratory has changed, is not clear cut, is self-generated, or overlaps the missions of other agencies, such competition, especially with the research-intensive universities, should be the norm;

  — The other area that circumvents merit-based competition involves Congressionally earmarked facilities and projects. Such facilities and projects, which are often intended only to satisfy particular interests, do not constitute a good investment for the nation. Instead, they waste federal funds, undermine morale, and destroy the integrity of the merit review process. The practice must cease and must not be initiated or encouraged by universities; and

- Finally, we note that priorities, by their very nature, are very sensitive to changes in the environment in which they are established. Criteria on which the priorities are based should, however, be much more stable and remain as suitable bases for new priorities appropriate to changed environments. Much more attention should therefore be focused on the development of criteria that this nation accepts as reflecting its long-term goals and aspirations and, as such, form an appropriate basis for the development of priorities at all levels and under all conditions.

Figure 7
University-Based R&D Support by Selected Federal Agencies (FY 1990)



Source: National Science Foundation

More than 20 different agencies of the federal government fund academic R&D. Their individually unique program goals dictate their respective funding levels and associated spending priorities. The comparison of the top six agencies and the aggregation "all others" highlights both the importance of biomedical research in U.S. national priorities and the special emphasis that the National Institutes of Health places in investigator-oriented research and basic research in particular.

Recommendation Four: Adjust Federal Support of Academic Research

The basic approach:

- Federal agencies should view their grants in support of university-based research — even when undertaken in support of a narrow mission — as an investment in the nation's future, and not just as procurement of goods and services. The federal science and technology agencies have a collective responsibility to make those investments. The view that it is "another agency's responsibility, not ours" is not acceptable;

- Grants in support of research should be seen by federal agencies, furthermore, not only as investments in new knowledge but as investments in the nation's scientific talent;

- Federal agencies should review the balance between their intramural research and the university-based extramural research that they support with a view to maximizing the amount of research conducted at universities, where human capital is generated in tandem with intellectual capital;

- The underlying principle that federal agencies should follow in awarding research funds to universities is, except in special circumstances, to cover the full costs — both direct and indirect — of the research programs they sponsor. In turn, the universities must commit to use these funds in the fulfillment of agreed-upon objectives; and

- Except in special circumstances, such as in the case of professional schools, federal agencies should gradually withdraw from the practice of paying a portion of the faculty salaries guaranteed by universities. Tenured faculty should have their academic year salaries paid by the universities, to avoid artificial expansion of teaching faculties dependent on federal sources for institutionally guaranteed salaries.

THERE IS NO BETTER METHOD FOR ENSURING QUALITY AND MAXIMIZING THE DIVIDENDS OF OUR INVESTMENT THAN FOR PROPOSED RESEARCH TO BE SUBJECTED TO COMPETITION BASED ON SCIENTIFIC MERIT.

- In making awards, federal agencies should:

  — avoid undue specificity in stating expectations regarding the outcomes of research projects;

  — accord principal investigators maximum flexibility under the law with respect to the choice of proposed research goals, and actual approaches, methods, and use of resources;

  — make longer-term (e.g., three to five year) awards, whenever possible;

  — award more block grants to give established research groups stable, flexible support; and

  — be more willing to accept risk in supporting unconventional ideas, especially if proposed by investigators with a sound record of accomplishments. This would especially include cases of experienced investigators moving into new research fields. In such cases, more emphasis should be placed on their achievements and promise than on the particular details of their first research proposals in a new area.

Indirect costs:

- The Executive Office of the President should strive to ensure that the indirect cost portion of research awards meets both the requirements of modern scientific inquiry and the responsibilities that attend stewardship of public funds. To that end,

  — indirect cost policies should be refined to ensure that actual reimbursements cover only legitimate overhead expenditures;

  — indirect cost rates should be negotiated at levels sufficient to provide full reimbursement for those overhead expenditures — especially facilities-related costs — that should be allocated to the research sponsored by the federal government; and

  — all federal agencies should be required to honor the negotiated rates in full when making research awards.

▪ Universities should be required to set aside and use the facilities and equipment portions of indirect cost payments for maintaining, refurbishing, and renovating the physical infrastructure and equipment required for research.

Facilities and other infrastructure:

▪ The federal government should establish a temporary, nationally competitive, merit-reviewed program of grants for repair and renovation of the physical infrastructure of university-based research, such as buildings, specialized equipment, and computer networks;

▪ The program should operate on a 50-50 matching basis with non-federal funding. The size of the program should be commensurate with the repair and renovation needs. Recent estimates place those needs at more than $4 billion;

▪ That program should operate no longer than a few years, only until universities can bring their facilities to an acceptable level of modernity. Regardless of where the responsibility might lie for the current obsolescence of many university research facilities, the nation cannot afford to have that situation continue or deteriorate further. Beyond the catch-up period, however, universities would be expected to keep their facilities current on the basis of federal indirect cost support and other resources; and

▪ The competitive, merit-reviewed program should make funds available only to institutions that pledge to forego funds earmarked for award without such review.

FEDERAL AGENCIES SHOULD VIEW THEIR GRANTS IN SUPPORT OF UNIVERSITY-BASED RESEARCH — EVEN WHEN UNDERTAKEN IN SUPPORT OF A NARROW MISSION — AS AN INVESTMENT IN THE NATION'S FUTURE, AND NOT JUST AS PROCUREMENT OF GOODS AND SERVICES.

Less red tape:

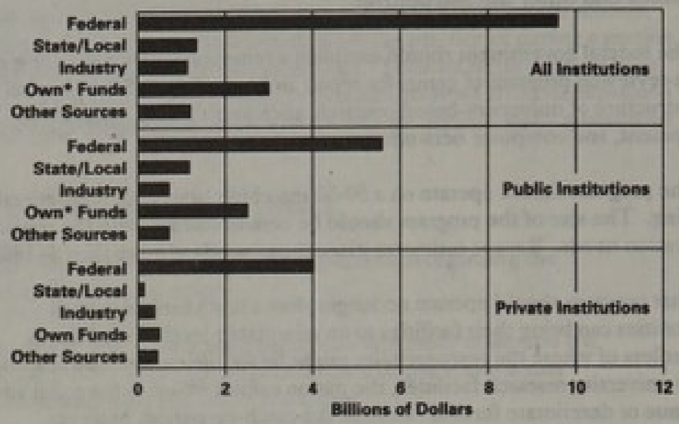
Federal agencies should strive to ensure that the administrative requirements associated with research awards to universities facilitate scientific inquiry rather than impede it. To that end:

▪ funding agencies should authorize their program staffs to make small, short-term grants at their own discretion for particularly promising proposals where quick response would be especially advantageous, using streamlined application procedures and without external review; and

▪ the Executive Office of the President should take the lead toward achieving federal government-wide uniformity and eliminating unproductive administrative requirements by reaffirming its support for the goals of the Federal Demonstration Project and promoting full participation by the relevant agencies.[2]

[2] The Federal Demonstration Project (FDP) is devoted to improving efficiency in the administration of research grants. The continuing objective of the project is to identify and eliminate unproductive requirements without compromising stewardship of public funds. Ten federal agencies and approximately fifty universities participate in the project. FDP is the only organized, long-term effort aimed at streamlining the basic administrative relationships linking the agencies sponsoring research with the institutions that perform it. Outcomes of the FDP demonstrations usually consist of recommended changes to federal government-wide policies provided by the Office of Management and Budget.

Figure 8
University-Based R&D Support by Source of Funds and Type of Institution, 1990



* Own funds for public institutions includes unknown amount of money from state sources.

Source: National Science Foundation

The federal government is the principal sponsor of university-based R&D. However, the federal share, which has essentially stable during the 1970s (near 67 percent), has been declining almost steadily since 1980, falling to 59 percent in 1990. The share financed by state and local government also shrank slowly throughout the 1980s while that financed from nongovernmental sources rose from 21 to 33 percent. Offsetting the contracting proportions provided by governments were the expanding proportions attributed to universities' own funds and industrial sponsors. The share of funding from all other sources (e.g., foundations) changed little from one year to the next, fluctuating around 7.5 percent.

Public and private universities exhibit some notable difference in the profile of their research support. The private universities are relatively more dependent on the federal government, whereas the public universities are more dependent on their "own" funds (see note underneath figure). The share of university-based R&D programs directly financed by state and local governments is higher for public universities than for private universities. In 1990, federal, state, and local governments together accounted for about two-thirds of university-based R&D at public universities and about three-quarters at private universities.

Federal Laboratories

Because federal support for research-intensive universities is affected by agency commitments to federal laboratories, PCAST believes there is now an urgent need to reexamine the roles of the more than seven hundred federal laboratories. As original missions have been accomplished, many of these laboratories have come to support basic research efforts lacking a clear relationship to mission objectives and in direct competition with research-intensive universities. These efforts typically have the benefit of superior resources, are not burdened by educational responsibilities, and are not subject to the same type of merit-review that ensures high standards of academic research. In some cases, new laboratories, in response to new missions, have been established when existing federal laboratories in other agencies are already setting the standards for activities in the fields covered.

Many of these laboratories continue to have appropriate and unique roles, including provision and operation of facilities beyond the scope of individual universities but invaluable to both university faculty and students. Under the impetus of the National Technology Initiative and similar programs, federal laboratories are forging new and productive linkages with U.S. industry. In the past, linkages between federal laboratories and universities were very strong, with a large flow of people back and forth among them and with resulting benefits in education and training. This flow has slowed, largely for bureaucratic reasons, and should be reestablished. It is appropriate to consider making all federal basic research support available for merit-based competition by universities, federal laboratories, or industry. Merit review in this case should include, as additional criteria, potential long-term contributions to economic well-being, national security, and education.

PCAST believes that a review of the federal laboratories similar to the present review of the research-intensive universities would be timely and would provide valuable input to the more general reexamination of the U.S. research and development enterprise that we discuss elsewhere in this report.

V. A Matter of Two Cultures: Universities and Industry

Senior management in industry must assure individuals who return to universities . . . that it is in the best interest of the corporation and the individual's career. This is not the case today. The university must be willing to take people who have not widely published . . . and are not recognized as the leading expert in a particular area. I believe both of these changes are possible. I believe the Nation will greatly benefit from this increased interaction.

William Spencer, President and CEO of SEMATECH
July 1992 statement to PCAST

DESPITE RECENT GAINS IN BUILDING LINKAGES BETWEEN U.S. UNIVERSITIES AND INDUSTRY, THERE ARE STILL TOO MANY INDIVIDUALS IN BOTH SECTORS WHO HOLD TO NEGATIVE PERSPECTIVES, ATTITUDES, AND STEREOTYPES ABOUT THE OTHER SECTOR.

Two very different cultures have surrounded industrial research and university research. In industry, the drive for new products and processes sets the agenda in applied research and provides the context for fundamental research. University research is driven by a wide range of factors, some involving practical problems confronting society, but many curiosity-driven and associated with the pursuit of knowledge with no obvious relevance to immediate practical problems.

Some of the cultural differences have had the unfortunate effect of unnecessarily inhibiting full interaction between industry and universities. The notion that each sector had its own well-delineated and isolated role and that new knowledge would flow as rapidly as necessary and in one direction from the universities to industry is completely at odds with today's world.

Today the pressure of international competition has introduced a critical time dimension into the system. For the nation's economic interests, the issue is not simply how much new knowledge is being generated but also how fast it is being translated into economically and socially beneficial products and processes. This argues for a more deliberate effort to move information and, especially, people between universities and industry.

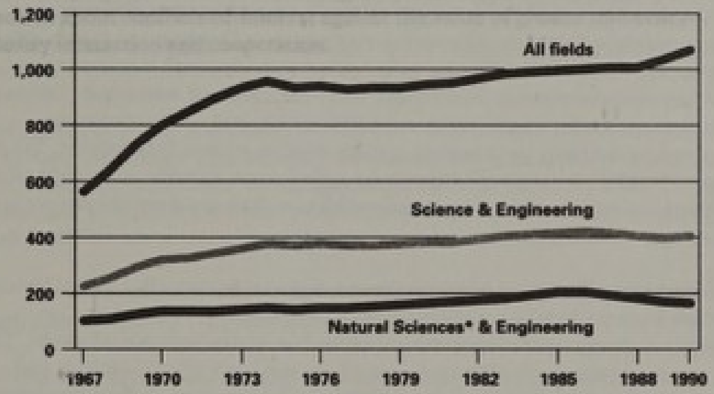
Over the past decade, substantial efforts have been made by federal, state, and local governments to foster greater and more effective ties between universities and industry. These efforts, which take the form of co-operative programs, research centers, and the like, should certainly continue. In addition, some scientific fields have developed in such a way that commercial applications derive more readily and rapidly from university-based fundamental research than was previously the norm. Biotechnology is the prime example, but a number of others could be cited.

The shrinking interval between fundamental research and industrial applications in certain areas also is serving to bring universities and industries together. Although these increasing linkages between the sectors have some potentially negative side-effects for universities, such as pulling faculty away from their teaching responsibilities or challenging strategic coherence at the institutional level, bringing universities and industry closer together in appropriate partnerships is, on balance, of enormous benefit to the nation.

Despite recent gains in building linkages between U.S. universities and industry, there are still too many individuals in both sectors who hold to negative perspectives, attitudes, and stereotypes about the other sector: new Ph.D.s who view taking a job in industry as "selling out" rather than following an academic calling; industry managers who are unwilling to send their best people to a university setting, even for a short time; faculty members who believe that their only educational mission is to train students for faculty positions and who channel their best students away from non-academic careers; industrialists who view university work as an intellectual luxury; academics who view industrial R&D as intellectually second rate.

The nation cannot afford to have this situation persist, and much more effort is required to overcome it. Even fundamental research that is not expected to yield short-term answers to industry's scientific problems can benefit from being informed by the technical concerns of industry. Conversely, U.S. industry should have the benefit of easy and immediate access to the new knowledge and new talent generated by universities. Exchange of personnel, at all levels, is the surest answer to these problems.

Figure 9
Bachelors Degrees by Broad Area of Study (Thousands of Degrees)

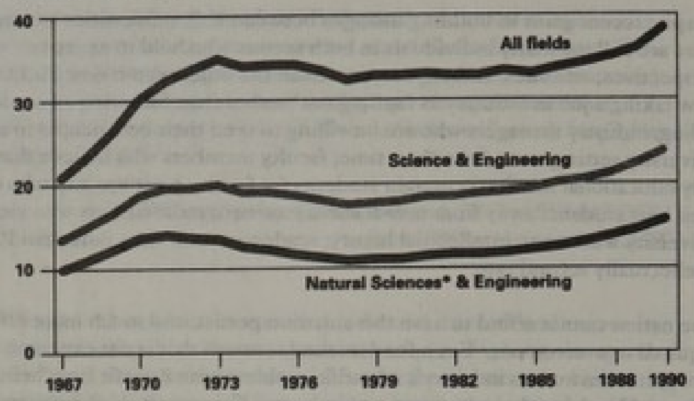


* Does not include medical and social sciences and psychology

Source: National Science Foundation and Department of Education

After rapid growth between the mid-1960s and the mid-1970s, the total number of bachelors degrees awarded each year remained essentially level until 1980, when growth resumed at a rate much slower than the earlier expansion. Over the same period, the annual production of bachelors degrees in the sciences and engineering grew more slowly than the overall trend.

Figure 10
Doctorate Degrees by Broad Area of Study
(Thousands of Degrees)



* Does not include medical and social sciences and psychology

Source: National Science Foundation and Department of Education

The total number of doctorates awarded each year exhibits a pattern similar to that for the bachelors degrees, albeit on a significantly smaller scale. However, the sciences and engineering account for a substantially larger fraction of the total doctorates than is the case for bachelors degrees and show a stronger upward trend in recent years.

Recommendation Five: Move People Between Industry and Universities

Accordingly, PCAST recommends that:

- universities and industry together, through a wide range of concerted actions, should exchange scientists and engineers at all levels — especially their very best — between the two sectors for substantial periods of time and repeatedly throughout their careers.

Specific activities and programs that contribute to that goal, and that should therefore be encouraged, include:

- undergraduate co-operative programs in industry;
- visiting professors from industry;
- dissertation research in industry laboratories;
- industry scientists mentoring graduate students; and
- faculty consulting for industry.

In sponsoring such activities, both industry and universities should seek the involvement of their most valued rather than their most expendable personnel. Both sectors will have to manage an increasing number of potential conflict-of-interest situations but, in doing so, should not stifle legitimate opportunities for greater interaction between university and industry personnel. In addition, any current or proposed federal or state regulation in this area should balance concerns about conflicts-of-interest against the value of greater university-industry interaction and cooperation.

VI. A Matter of the Best Scientific Talent: Tapping the Nation's Talent Base

Quite apart from the matter of fairness is the realization that we do not ever have enough bright, scientifically-minded young people to deprive any of them of a chance for a good education and viable career opportunities.

Barbara Webster, Professor, University of California - Davis
July 1992 statement to PCAST

POTENTIALLY BRILLIANT YOUNG PEOPLE CAN BE FOUND THROUGHOUT THE POPULATION, WITHIN BOTH GENDERS AND EVERY RACE AND ETHNIC GROUP, IN EVERY ECONOMIC SITUATION, AND IN EVERY REGION OF THE COUNTRY.

Most important scientific discoveries were made by a small number of very gifted people who were provided the opportunity and time to pursue their intellectual interests. Potentially brilliant young people can be found throughout the population, within both genders and every race and ethnic group, in every economic situation, and in every region of the country. Stronger public policies must be designed to identify scientifically-gifted people at an early age and help them develop their talents, no matter what their circumstances.

Many factors influence the development of scientific and technological talent in the population. Most are beyond the scope of this report, but a few bear mentioning — high societal levels of maternal and child health, early learning programs, the availability of role models, competent science and mathematics teachers in the early grades, and the sympathetic portrayal of scientists and engineers in the media. Several of these factors, along with recommendations for federal action, have been dealt with in the recent PCAST report on "Learning to Meet the Science and Technology Challenge."

A range of local efforts, stimulated, for example, by a Department of Education program, are made to identify and help "gifted and talented" elementary and secondary school students. In addition, there are local and nationwide "science-fair" type competitions, national merit scholarships, and similar programs sponsored by industry, local or state government, or private foundations. While very worthwhile, these do not seem to be sufficient to identify, or provide support for, a high enough number of talented students to pursue careers in science and technology.

Japan and many European countries have a highly selective educational structure in which large proportions of students are systematically "weeded out" at relatively early ages and cannot easily proceed on to university-level work. The U.S. system has multiple reentry points where students whose interests and talents develop later than the norm, or whose circumstances change, can pursue their original or new educational goals. Too many promising students turn away from science at some early or middle stage of their education, only to find later that, despite the possibility of re-entry, "catching up" is quite difficult. Better ways must be found to reach out to these students and help them continue their educations.

Several types of federal and non-federal loan and grant programs are available for undergraduate support, but some students may not be able to qualify or may not be able, even with these programs, to afford to attend institutions of the caliber corresponding to their talents and interests. Portable undergraduate scholarships, by contrast, would allow a higher proportion of especially talented students to choose the schools that they wish to attend.

A student testifies before PCAST at one of six public meetings held nationwide.

At the graduate level, competitive, merit-based federal support for portable fellowships has enabled thousands of bright men and women to complete the doctoral degree and go on to become outstanding teachers and researchers in academia, industry, and government. Because they do not have to seek support as research assistants or teaching assistants, these fellowship holders may choose to attend — and are welcomed by — any university in the nation.

Changes to the federal tax code in 1986, and related actions by state and local authorities, have resulted in greatly increased taxation of scholarships, fellowships, and student stipends for research. Examples include payments for participating in hands-on undergraduate research sponsored by the National Science Foundation and summer participation at federal laboratories. Such taxation discourages students from accepting such support, complicates administration for the universities and the sponsoring authorities, and causes sponsors to raise payments — which reduces the number of persons they can sponsor.

If the United States is to continue to lead the world in basic scientific discoveries and in their exploitation, we will need to identify the most talented young people at the earliest possible time, encourage their interest in advanced education and science, and give them a sense of purpose as they pursue their education and career paths.

Recommendation Six: Identify and Nurture the Best Talent

Considering that potential science and engineering talent is distributed throughout the population, in diverse economic circumstances, and in every part of the country, PCAST recommends that:

- the federal government develop programs to award substantial numbers of portable undergraduate scholarships and graduate fellowships in science and engineering in each Congressional district. These awards would be made on a nationally competitive basis, using non-political, merit criteria, and would be designed to encourage greater numbers of outstanding students — throughout the nation — to pursue training, and then careers, in science and engineering.

As with the traditional program of National Science Foundation graduate fellowships, only citizens and permanent residents would be eligible; awardees would be able to attend any U.S. institution of their own choosing; and reasonable allowances would be included to cover institutional costs. The undergraduate program would include both beginning students and some who have completed one or two years of undergraduate work.

Moreover, PCAST notes that federal, state, and local tax policies should bolster, not undermine, the nation's investments — both public and private — in human capital. PCAST recommends that:

- federal, state, and local government end all taxation of scholarships, fellowships, and stipends for student participation in research.

Research-intensive universities can have a major effect on the development of scientific talent by educating inspiring teachers of precollege science and mathematics. PCAST, therefore, recommends that:

- research-intensive universities give greater emphasis to the education (including continuing education) of precollege teachers of science and mathematics; and

- the federal government provide scholarships or service-repayable loans to encourage talented students to attend research-intensive universities for careers as precollege teachers of science and mathematics.

Beyond the Horizon

This report is intended to address pressing problems that threaten the productive relationship between the federal government and research-intensive universities. We believe that the fundamental premises of this relationship are sound but that improvements are required for it to avoid deterioration and achieve its fullest potential.

We recognize the present time as one of tumultuous and profound changes in American society and in the world. The ending of the Cold War, the emergence of the European Community and nations of the Western Pacific Rim as economic powers, the changing demography of the American population, the ever increasing power of science and technology, and the growing awareness of new societal problems to which science and technology can be applied all require fresh and creative thinking of overall federal science and technology policy of which federal government-university relations are a part. While the current framework has served us well for four decades, it is far from obvious, as we move into the swifter current of the twenty-first century, that it will retain the validity it had when it was established in the middle of the twentieth century.

In our view, we must look beyond the immediate issues addressed in this report and conduct a broad national reexamination of the place of research and development in our national life — including its fundamental rationale, goals, organization, funding, and administrative mechanisms. The importance of generating new knowledge and new technologies and of educating scientists, engineers, and the general public for the twenty-first century demands no less. It is the intention of PCAST, drawing fully on federal and state government as well as private sector expertise and experience, to undertake such a reexamination in a subsequent report.

. . . IT IS FAR FROM OBVIOUS, AS WE MOVE INTO THE SWIFTER CURRENT OF THE TWENTY-FIRST CENTURY, THAT [THE CURRENT FRAMEWORK] WILL RETAIN THE VALIDITY IT HAD WHEN IT WAS ESTABLISHED IN THE MIDDLE OF THE TWENTIETH CENTURY.

APPENDIX A

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APPENDIX B

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We would particularly like to express our appreciation to the following persons who so generously hosted and helped to organize our public meetings, and presented their views on many of the topics discussed in the report.

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OTHER REPORTS

In addition to *Renewing the Promise: Research-Intensive Universities and the Nation*, the President's Council of Advisors on Science and Technology has also produced Panel reports on a variety of other science policy topics. Copies of the six Panel reports listed below may be obtained free of charge from The Office of Science and Technology Policy, Executive Office of the President, Washington, D.C. 20506; (202) 395-4692.

Achieving the Promise of the Bioscience Revolution: The Role of the Federal Government
Daniel Nathans, Chairman

High Performance Computing and Communications Panel Report
Solomon Buchsbaum, Chairman

LEARNING to Meet the Science and Technology Challenge
Peter Likins, Co-chairman
Charles Drake, Co-chairman

Megaprojects in the Sciences
John McTague, Chairman

Science, Technology, and National Security
Solomon Buchsbaum, Co-chairman
John S. Foster, Co-chairman

Technology and the American Standard of Living
Ralph Gomory, Chairman

Mr. BOUCHER. Thank you very much, Dr. Nathans.

Dr. Rushton?

Dr. RUSHTON. Mr. Chairman, is this microphone on? There's no switch.

Mr. BOUCHER. Yes, it is.

Dr. RUSHTON. Thank you.

Mr. Chairman, it is my pleasure to offer an industrial perspective on science policy in this country, and in particular on the role of the National Science Foundation. These hearings are most appropriate at this time. I'm certain they will affect the future vitality of science and technology in the United States.

In that respect, I'm speaking as the current president of the Industrial Research Institute, an associate of some 260 major industrial corporations that carry out over 80 percent of the industrial research and development in the United States. My remarks are based in part on a recent survey of the IRI membership in regard to the future direction of the National Science Foundation. The focus of these remarks will be on how the academic research enterprise contributes to the needs of industrial R&D.

Mr. Chairman, I wish to emphasize two important background points as background remarks. One is that industry each year allocates less than 5 percent of its R&D effort to basic research. The other is that the success of our industrial R&D enterprise depends upon the quality of the people employed in this enterprise, people from colleges and universities in our country. We can conclude, therefore, that industrial R&D depends upon American colleges and universities for an unending supply of new knowledge and an ample supply of well-trained scientists and engineers.

The importance of this supply of knowledge and people is reflected by the impressive increase in industrial support of academic R&D over recent years. In addition, there has been strong interaction by industry with the Centers Program of the National Science Foundation.

Industry support of academic R&D went from some $699 million in 1986 to $1.25 billion in 1991, a five-year increase of 79 percent and an annual growth rate of over 11 percent. This growth in funding of academic R&D occurred at the same time that the growth rate in overall spending for industrial R&D was less than 5 percent. I believe it demonstrates the responsiveness of industry in general to NSF's initiatives.

Mr. Chairman, I should now like to share with you the highlights of a recent survey of the IRI membership on the future directions of the National Science Foundation. We began with a question on the effectiveness of NSF programs in accelerating the transfer of knowledge from universities to industry. Our membership believes that the concept of involving industry with universities should be strongly encouraged. However, it was emphasized by many that the primary role of universities should be to educate those students, and that basic research, as well as interaction with the private sector, can and should be supportive of that role.

Transferring knowledge to industry, albeit very important to the needs of industry, was considered, nevertheless, of secondary importance. It was noted that it is the role of industrial R&D to combine people and knowledge in order to develop and produce improved products, processes, and services for the benefit of society. This role is, of course, the process of innovation.

Our members also encouraged that more exchange programs in which academic researchers work in an industry, and vice versa. Such programs were viewed as an effective means of interaction not only to transfer knowledge, but to promote understanding of each other's roles in our country's global competitiveness. Thus, we urge that programs of this nature be supported by NSF.

Other suggestions included industry sponsorship or mentorship, if you will, of NSF projects; the encouragement of additional joint proposals from universities and companies; industrial steering committees for selecting projects; and new techniques for communication of industry's long-term needs to universities.

The second question in our survey asked for opinions on the usefulness of today's academic research compared with that of a decade or two ago. That is, has NSF been focusing its limited resources on the right problems? Although historic comparisons may be difficult, our members agreed that academic research findings were, indeed, more relevant and useful to industry today than 10 or 20 years ago. Universities were viewed as more receptive to and interested in collaborating with industry at this time. It was emphasized, however, that NSF should focus its programs on the long-term scientific and engineering needs of the United States, and that a coordinated plan should be developed with input on those needs from industry and other sectors. That plan is, of course, the point of these hearings, and we commend you, Mr. Chairman, for convening them.

Two other areas were covered by our survey: the implication of more partnerships between industry and universities and whether or not recent graduates have been adequately prepared for work in industry. We noted general agreement among the IRI members that partnerships should be encouraged but not forced. Industry has limited capacity to allocate personnel and resources for interaction with both the academic community and Federal laboratories. We would suggest that the value of the academic research enterprise should drive industry's interest in collaborations. The purpose of this: intellectual proprietary protection should be assured if industry provides a significant share of the funding to carry out the work.

The technical competence of recent graduates was judged to be as high as it has ever been. However, some concern was expressed about the ability of graduates to communicate effectively, to work as part of a team rather than as individuals, and to complete projects in a timely fashion. It was also noted that at least one course of ethics should be part of every college curriculum. NSF's attention to these concerns will be greatly appreciated by my colleagues in industrial research.

Mr. Chairman, I wish to conclude my remarks at this time. My full testimony goes into more detail than time has allowed me to cover this morning.

Finally, on behalf of the IRI, Mr. Chairman, I appreciate the opportunity to offer these comments and will be pleased to respond to any questions that you may have. Thank you.

[The prepared statement of Dr. Rushton follows:]

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March 3, 1993

Mr. Chairman, it is my pleasure to offer an industrial perspective on science policy in this country and, in particular, on the role of the National Science Foundation. These hearings are most appropriate at this time because the current debates about limited financial resources, budget cuts, and possible increased taxation could be a watershed for the future vitality of science and the technology in the United States.

I am speaking as the current President of the Industrial Research Institute, an association of some 260 major industrial companies that carry out over 80% of the industrial R&D in the United States. IRI was founded in 1938 and was part of the National Research Council until it became independent in 1945. Our Mission, which is to enhance the effectiveness of industrial research, is supported by six purposes, one of which is to generate understanding and cooperation between the academic and industrial research communities. Thus, I am delighted that we were invited to contribute to these important hearings.

My remarks are based in part on a recent survey of the IRI membership in regard to the future direction of the National Science Foundation. The focus of these remarks will be on how the academic research enterprise contributes to the needs of industrial R&D. However, I shall begin by putting the industrial R&D enterprise in perspective and briefly describing some of the ways that industry supports academic research. I will conclude with suggestions on how government, and the National Science Foundation, can enhance the technological competitiveness of American industry into the next century.

IRI estimates that expenditures on industrial R&D in the United States this year will be approximately $115 billion. Of this amount, some $83 billion will come from industry's own funds and the balance of $32 billion will come from government agencies, such as DOD, DOE, and NASA. As the average R&D to sales ratio for industry is about 3.3%, the $83 billion from industry represents company sales of over $2.5 trillion, or more than 40% of the Gross Domestic Product. IRI's most recent R&D trends forecast showed that R&D spending and employment will grow only slightly in 1993, continuing a pattern of little or no real growth since 1986.

The overriding purpose of industrial R&D is to stimulate innovation, that is, the process of creating new knowledge and transforming this knowledge into new products, processes, or services that meet market needs. Innovation creates new businesses and new jobs, and is the responsibility of private enterprise. Innovation is the fundamental source of growth and wealth in society. Nearly three-quarters of the industrial R&D effort is directed toward development activities, such as product and process prototypes, design, testing, and pilot-plant operations. About one-quarter is spent on exploratory, or applied research, which is work directed toward gaining new knowledge related to existing or planned products or processes. Less than 5% of industrial R&D is allocated for basic, or fundamental research, which we define as original, experimental, and/or theoretical investigations to advance human knowledge, without specific commercial objectives.

Industrial R&D is carried out by nearly 750,000 scientists, engineers, technicians, information specialists, and managers in some 10,000 laboratories across the country. It is by far the most elaborate and sophisticated research enterprise in the world. Companies such as General Electric, Monsanto, Du Pont, Procter & Gamble, and General Motors not only have central research facilities, but from 10 to 40 divisional laboratories. The success of this enterprise depends first and foremost on the quality of the people in them.

Mr. Chairman, I wish to emphasize two important points from these background remarks. One is that industry allocates only a small fraction of its R&D effort on basic research. The other is that the success of our industrial R&D enterprise depends on the quality of the people employed in this enterprise--people from colleges and universities in our country. We can conclude, therefore, that industrial R&D depends on American colleges and universities for an unending supply of new knowledge, and an ample supply of well-trained scientists and engineers.

The importance of this supply of knowledge and people is reflected by the impressive increase in industrial support of academic R&D over recent years. In addition, there has been stronger interaction by industry with the Centers Programs of the National Science Foundation. According to the National Science Board's 1991 "Science & Engineering Indicators," industry support of academic R&D went from $699 million in 1986 to $1.25 billion in 1991, a five-year increase of 79% and an annual growth rate of over 11%. This growth in funding of academic R&D occurred at the same time that the growth rate in overall spending for industrial R&D was less than 5%.

Financial support and involvement from industry are among the requirements for NSF sponsorship of its Engineering Research Centers and its Science and Technology Centers. Industry has responded well to these requirements since the Centers Programs were implemented by NSF in the 1980's. Hundreds of companies are actively involved in these programs. In some cases, the Centers bring together companies that are traditionally strong competitors to gain fundamental knowledge on physical mechanisms, as exemplified by Kodak and Xerox in the Photonics Center at the University of Rochester.

Mr. Chairman, I should now like to share with you the highlights of a recent survey of the IRI membership on the future directions of the National Science Foundation. We began with a question on the effectiveness of NSF programs in accelerating the transfer of knowledge from universities to industry. Our membership believes that the concept of involving industry with universities should be strongly encouraged. However, it was emphasized by many that the primary role of universities should be to educate their students and that basic research as well as interaction with the private sector can support that role. Transferring knowledge to industry, albeit important to the needs of industry, was considered of secondary importance. It was noted that it is the role of industrial R&D to combine people and knowledge in order to develop and produce improved products, processes, and services for the benefit of society.

Our members also encouraged more exchange programs, in which academic researchers work in industry, and vice versa. Such programs were viewed as an effective means of interaction, not only to transfer knowledge, but to promote understanding of each others' roles in our country's global competitiveness. Thus, we urge that programs of this nature be supported by NSF. Other suggestions included industry sponsorship, or mentoring, if you will, of NSF projects; the encouragement of additional joint proposals from universities and companies; industrial steering committees for selected projects; and new techniques for communication of industry's long-term needs to universities.

It is important, I believe, to note that industry's needs are changing because of shorter product cycles and the globalization of markets. A six-months' lead time in the market can be crucial to commercial success. The compatibility of products with local customs and tastes can also be crucial to commercial success. These needs are often inconsistent with the pace and scope of university research, and should be kept in mind in planning future NSF programs.

The second point of our survey asked for opinions on the usefulness of today's academic research compared with that of a decade or two ago; that is, has NSF been focusing its limited resources on the "right" problems? Although historic comparisons may be difficult, our members agreed that academic research findings were indeed more relevant and useful to industry than 10 or 20 years ago. Universities were viewed as more receptive to and interested in collaborating with industry at this time. It was emphasized, however, that NSF should focus its programs on the long-term, strategic needs of the United States in science and engineering, and that a coordinated plan should be developed, with input on those needs from industry and other sectors. That plan is, of course, the point of these hearings, and we commend you, Mr. Chairman, for covening them.

Two other areas were covered by our survey--the implication of more partnerships between industry and universities, and whether or not recent graduates have been adequately prepared for work in industry. We noted general agreement among IRI members that partnerships should be encouraged, but not forced. Industry has limited capacity to allocate personnel and resources for interaction with both the academic community and our Federal laboratories. We would suggest that the value of the academic research enterprise should drive industry's interest in collaborations. Intellectual property protection should be assured if industry provides a significant share of the funding to carry out the work, and royalties or licensing fees should be payable to the university and perhaps individual investigators.

The technical competence of recent graduates was judged to be as high as it has ever been. However, some concern was expressed about the ability of graduates to communicate effectively, to work as part of a team rather than as individuals, and to complete projects in a timely fashion. It was also noted that at least one course on ethics should be part of every college curriculum. NSF attention to these concerns will be greatly appreciated by my colleagues in industrial research.

Mr. Chairman, I wish to conclude my remarks by again emphasizing the following points:

- Our academic research enterprise is a valuable national asset in helping to meet industry's needs for new knowledge and human resources.
- The primary role of universities should be education.
- University research should focus on basic research in science and engineering, rather than applied research or development.
- The Federal government should encourage industrial support of graduate education and university research.
- Industry should continue to be consulted on the future direction of National Science Foundation programs, just as you have done today.

- Finally, in view of the modified mission of the National Science Foundation, calling for more linkages and collaboration in all NSF programs, industry representation should be more visible on the National Science Board.

On behalf of IRI, Mr. Chairman, I appreciate the opportunity to offer these comments, and will be pleased to respond to any questions that you may have.

* * *

The Industrial Research Institute is an organization of more than 260 major industrial firms having common interest in the effective management and conduct of industrial research and development. IRI member companies invest over $55 billion annually in R&D, representing more than 80% of the Nation's privately funded effort. These companies, spanning diverse industries, compete in the global marketplace and provide jobs for more than 10 million of America's workers. Together they generate well over $2 trillion in annual sales, representing one third of our gross domestic product.

IRI welcomes the opportunity to discuss further its views on these important initiatives. For additional information, please contact Mr. Charles F. Larson, Executive Director, Industrial Research Institute, 1550 M Street NW, Washington, DC 20005 (202-872-6350).

Mr. BOUCHER. Thank you very much, Dr. Rushton.

Dr. Stever?

Dr. STEVER. Mr. Chairman, thank you very much.

Mr. BOUCHER. If you could turn your microphone on, we'll hear you a bit better. Thank you.

Dr. STEVER. Mr. Chairman, thank you very much for this opportunity to testify at this important hearing. You have asked me to focus my remarks on the specific changes needed to the mission of the National Science Foundation which is supported by the report of the Carnegie Commission Task Force on Establishing and Achieving Long-Term Goals entitled, "Enabling the Future: Linking Science and Technology to Societal Goals," and to comment on the recommendations by the NSB Commission report, "A Foundation for the 21st Century."

I hope you will—I wish you would introduce my testimony and also our report into your records.

Mr. BOUCHER. Without objection, it will be made a part of the record.

Dr. STEVER. Thank you very much, and I will try to leap through this to save some time.

First of all, well, let me say that our report, "Enabling the Future," has several themes. The first theme is—develops around this unusually long time which elapses from scientific discovery to the supply of products, processes, or procedures that can be used in some noteworthy way by society in achieving progress toward its goals. Could we as a nation be more effective if there were closer linkages between the science and technology goals and the societal goals which depend on progress in science and technology? I would refer you to the chart that is at the end of our testimony which has two boxes. The final page—and I think I can speak best about that around those charts. One is labeled "Box 5," the policy areas which would benefit from the articulation of long-term S&T goals and relating them to societal goals.

We have a list of 12 areas in which science and technology are going to play very important roles in societal goals, not the central role always, but very important. And 10 of them, the first 10—environment and natural resources, health and social welfare, economic performance, food production and distribution, energy supply and utilization, national and international security, basic and continuing education, transportation, public infrastructure, and telecommunications and information management—those areas are the areas which have mission agencies supporting them and which will call very heavily on what you call a needs-directed research. And we believe that focusing on that relationship in the long term—every year we get budget which is a long-term policy statement, although it isn't called that, and it often neglects some of the long-term connections between the science and the goals of society, and we think a much better job can be done there.

Now, secondly, a second theme is that the last two of these policy areas—that is, the basic—I'm sorry, exploration and expansion of knowledge, and the S&T base, including facilities and personnel—differ from the others. Those—that—the science and technology base clearly is something on which all of the other, the needs-directed research is going to depend upon. It's going to depend upon it for its people, its basic ideas, scientific literacy in the public. It's going to depend upon it for the facilities and institutions and diffusion of scientific and technical knowledge.

We believe that a very good future role for the National Science Foundation would be to take the principal responsibility in the long-term health of the science base as we list it here. I was delighted to see in the testimony this morning that the final comment by the Commission of the National Science Board talked about the return of the role of the Board in influencing a stronger science and engineering technology policy for the Nation. Just assuming the responsibility for the health of that science base would in itself be an immense step in the direction of that flow.

There is one other thing that we have in our report, and that is that we have recommended that long-term S&T goals should be scrutinized by a broadly-based societal representative group and not left solely to those from the science community itself. And I think we discovered in the report that you heard this morning on a Commission which is based exactly that way what fine work could be done on a larger policy issue of science and technology, and I think we'd propose that a forum be established of that type and it explore and seek consensus on long-term S&T goals and the potential contribution of scientific and engineering advances to the achievement of societal goals.

We suggested two options. One is that this forum be administered and convened by the National Academy's complex or the other option was a new, independent nongovernmental organization.

Let me say only one other thing, Mr. Chairman. You have asked the question about how can the National Science Board and Foundation determine priorities between needs-oriented or needs- driven and curiosity-driven research. I believe that they'll do it just exactly as they have all along. They do it from wisdom. They do it from experience. They do it from checking with others. They do it from an analysis of the outer world, but they have to do it themselves, and judgment is the final word.

Now I would hope that the NSF still remains centrally in the curiosity-sponsored research where they have really proven themselves completely, and I do not believe that we can do without that. If we don't have it in the long run, all of the rest withers.

I will conclude my remarks by complimenting you and wishing you well on your very broad mission with two agencies, OSTP and NSF, for which I have a very warm feeling in my heart, and also your broad science policy role.

[The prepared statement of Dr. Stever follows:]

TESTIMONY of H. GUYFORD STEVER, CHAIRMAN

CARNEGIE COMMISSION TASK FORCE

on

ESTABLISHING and ACHIEVING LONG TERM GOALS

to

THE SUBCOMMITTEE on SCIENCE

of

THE COMMITTEE on SCIENCE, SPACE, and TECHNOLOGY

U.S. HOUSE of REPRESENTATIVES

MARCH 3, 1993

Mr. Chairman and Members of the Subcommittee:

Thank you for the opportunity to testify at this hearing "to examine the recommendations for change in the mission of the National Science Foundation (NSF) that are contained in the report of the National Science Board (NSB) Commission on the Future of the NSF." You have asked me to focus my remarks on the specific changes needed in the mission of the NSF which are supported by the report of the Carnegie Commission Task Force on Establishing and Achieving Long Term Goals, Enabling the Future: Linking Science and Technology to Society Goals, and to comment on the recommendations of the NSB Commission report, "A Foundation for 21st Century.

At this time of change, your Subcommittee has unparalleled opportunities and awesome responsibilities with your assignments of the authorization and oversight of both the Office of Science and Technology (OSTP) and the National Science Foundation, as well as that of the broad overview of science policy. In that latter role, and in answer to your question, "What should the role of the National Science Board be in the development of a coherent national science and technology policy?", I believe the Administration and the Congress should implement completely the recommendation and statements in the next to last paragraph of the NSB Commission report;

> "Finally, the Commission returns to the role of the Board in influencing a stronger science and engineering and technology policy for the Nation. The Board and the National Science Foundation are today the lead organizations representing the interests of broad science and engineering

in the United States. The Board must work with its peers in the private and public sectors so that the Nation might formulate a much needed science and technology road-map. We are convinced that students, scientists, engineers, industry, and the public would join together to build, and build on, that roadway."

If the Board were given and accepted fully this broader role, it would return to Vannevar Bush's original concept of the Board's role as presented in SCIENCE: THE ENDLESS FRONTIER. At the beginning of NSF's operations, that broader role was thought to be too much for the fledgling NSB. Instead the Board and the NSF settled on the another very important role given in Dr Bush's report, that of supporting research in the universities, taking advantage of the symbiotic relationship between research and teaching and the relative freedom of inquiry in the academic environment.

This research funding role has been performed very successfully by NSF, but the Nation has at times lacked a strong agency voice for the broad science policy parts of the science and technology policy area. The broader role of leadership in the formulation of science policy and coordination of the governments programs of science, though it was initially in the NSF's establishing act, now is in that of the OSTP, the National Science and Technology Policy, Organization and Priorities Act of 1976. It all comes under the purview of this Subcommittee which now truly has a very broad responsibility, covering the OSTP, the NSF with a re-enlivened Board, and science policy generally.

The First Theme of Enabling the Future

Our Carnegie Commission report, Enabling the Future: Linking Science and Technology to Societal Goals, develops several themes. The first relates to the usually long time which elapses from a scientific discovery to the supply of products, processes or procedures that can be used in some worthwhile way by society in achieving progress towards its goals. Could we as a nation be more effective if there were closer linkages between the science and technology goals and the societal goals which depend on progress in science and technology? We conclude that there should be much stronger linkages. Our recommendations on this point is to make the annual science and technology budget the focal point for action of linking long-term S&T goals to long-term societal goals. We recommend that all the agencies involved in the S&T budgeting process should make clear the linkages in their budget presentations. One of our recommendations is to Congress: "Congress should devote more explicit attention to long-term S&T goals in its budget, authorization, appropriation and oversight procedures."

I include here a list, from our Goals report, of twelve policy areas to which S&T contribute in important ways, and in which linkages of S&T goals can be made to societal goals. Research done directly aimed at any of the first ten of those policy areas would be what you referred to in your letter as `needs-driven (i.e.,strategic) research'. Most of what you referred to as `curiosity driven research' would be part of the 11th, exploration and expansion of knowledge, and of the 12th, the science base.

The Second Theme of Enabling the Future

A second theme of our report is that the science base policy area is different from the other simply because it underpins all the S&T activity of all the policy areas. Without strength in the science base, progress generally will wither. Its components, which are given in an accompanying chart taken from our Goals report, are: general science and mathematics education; scientific literacy of the public; higher education in science, engineering and the social sciences; human resources (scientists, engineers,and technical personnel); facilities and institutions; scientific research and development of generic technology; diffusion of scientific and technical information.

In answer to your question, "..are changes required in the mission of the NSF?", I would suggest that direct assignment to the NSF of the responsibility for the health of the science base policy area would be appropriate. I am pleased with the NSB Commission's education recommendations which strongly affirm that NSF's education role should be broadly based and strengthened. This would ensure that the NSF would better cover more of the science base than only the research part where NSF is already strong.

Other than that assignment, I do not think that NSF's mission needs change. It is remarkably flexible already, enabling experimentation with such funding arrangements as the engineering research centers, establishing national facilities to be operated by consortia in such fields as astronomy, atmospheric sciences, etc., university and industry cooperative research, and many others. It should be kept flexible, allowing NSF authority to continue to experiment with new conceptual and institutional arrangements for the conduct of research.

In answer to your question, "How should NSF achieve the `appropriate balance' between NSF's support for curiosity driven research and needs-driven (i.e. strategic) research recommended in the Commission's report?", my answer is to use the same balancing techniques that they use in deciding the relative budget changes to make between different scientific disciplines--apply wisdom, experience, advice, peer review, etc. in judging the worth of the research proposals; make sure that a mission agency would not be better equipped the successful proposals and act as the NSF does in the gap-filling role on the funding of research proposals of all kind.

A further point to make concerning the appropriate balance concern is that the greatest effort of NSF should be in curiosity driven research where it has long experience, great success, and most important a unique agency mission to cover all the fields of science. There are many mission agencies pursuing their own needs driven research, so NSF should participate only when some gaps in the total coverage are noted, or when there is an exceptional idea emerging that is not picked up by the mission agencies. If some programs of needs-driven research grow too large, they can be transferred to a mission agency. I recall that the NSF was assigned the lead agency role in solar energy research in the early 1970s, a program which ballooned to almost $100 million following the oil embargo crisis of late 1973. NSF transferred it to the Energy Research and Development Agency and went about its other business.

The Third Theme of <u>Enabling the Future</u>

A third theme of our Carnegie Commission goals report is that long-term S&T goals should be scrutinized by a broadly based societal representative group, and not left solely to those from the science community itself. Specifically we recommend, "A nongovernmental National Forum on Science And Technology Goals be established to facilitate the process of defining, debating, focussing, and articulating science and technology goals in the context of federal of federal, national, and international goals, and to monitor the development and implementation of policies to achieve them." The Forum would convene individuals from industry, academia, nongovernmental organizations, and the interested public to explore and seek consensus on long-term S&T goals and the potential contribution of scientific and engineering advances to the achievement of societal goals. We suggested two options for administering the Forum: the National Academies Complex; or a new independent, nongovernmental organization. We have explored this with the leaders of the National Academies, and find they are interested if funding can be obtained. They believe, and we agree, that their experience at gathering diverse interested groups to work on a S&T problem with broad societal implications is well proven in several of their activities of recent years.

As we defined the Goals Forum concept in our report, we recognized the importance of the funding source. A private source would lend the capability of flexibility of operation, especially during start-up. Public funding would provide the interest of government agencies in receiving the finished works of the Forum. A mixture of both in tne long run might prove best.

In conclusion, Mr. Chairman and members of the Subcommittee, I thank you for the opportunity to appear here today. The Carnegie Commission on Science, Technology, and Government approved the Panel's report, Enabling the Future, and it is part of my testimony today. The remarks in this written testimony contains many of my own thoughts drawn both from the report and from my experiences at NSF and OSTP.

Box 3. Major Components of the Science and Technology Base

- General science and mathematics education
- Scientific literacy of the public
- Higher education in science, engineering, and the social sciences
- Human resources (scientists, engineers, and technical personnel)
- Facilities and institutions
- Basic research and development of generic technology
- Diffusion of scientific and technical information

Box 5. Policy Areas That Would Benefit from the Articulation of Long-Term S&T Goals

- Environment and natural resources
- Health and social welfare
- Economic performance
- Food production and distribution
- Energy supply and utilization
- National and international security
- Basic and continuing education
- Transportation
- Public infrastructure
- Telecommunications and information management
- Exploration and expansion of knowledge
- S&T base (including facilities and personnel)

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ENABLING THE FUTURE

LINKING SCIENCE AND TECHNOLOGY TO SOCIETAL GOALS

SEPTEMBER 1992

A Report of the

CARNEGIE COMMISSION
ON SCIENCE, TECHNOLOGY, AND GOVERNMENT

CONTENTS

FOREWORD

It has been nearly a half century since Vannevar Bush provided President Franklin Roosevelt his visionary report on the future of science and technology. At the time that *Science—The Endless Frontier* was published, the Second World War, the driving force behind many scientific and engineering accomplishments, had just ended and the United States faced fundamental questions about the interactions of universities, industry, and government in furthering science and technology. In Bush's words, "The government should accept new responsibilities for promoting the flow of new scientific knowledge and the development of specific talent. . . ." Science, Bush argued, should serve society, and in turn, society should provide the financial support to assure the advancement of science, particularly basic research. Today, with the end of the Cold War and the major fiscal challenges facing our nation, we are again asking ourselves about the role of science in society.

Science is indeed an "Endless Frontier"—each advance, large or small, builds on those of the past and provides a foundation for the accomplishments of the future. No one can predict the future of science. As this report points out, science is a voyage of discovery, and as Joseph Priestley wrote in the late 1700s, "in completing one discovery we never fail to get an imperfect knowledge of others of which we could have no idea before."

No one can accurately predict the future of science, but the collective ingenuity of scientists and engineers can be directed toward the challenges facing society. In a sense, science can be the vehicle that drives us to the future, but society must articulate the general direction in which it wishes to go. This report suggests some practical approaches to linking science and technology to the goals of our nation. We hope that these approaches will help catalyze an ongoing discussion among scientists, engineers, and other individuals throughout society about our long-term national goals and the ways that science and technology can contribute in achieving them.

William T. Golden, Co-Chair
Joshua Lederberg, Co-Chair

PREFACE

This report of the Carnegie Commission on Science, Technology, and Government was prepared by its Task Force on Establishing and Achieving Long-Term Goals and was adopted by the Commission at its meeting on June 30, 1992. The members of the Task Force were:

H. Guyford Stever, Chair	Rodney W. Nichols
Harvey Brooks	James B. Wyngaarden
William D. Carey	Charles A. Zraket
John H. Gibbons	

Senior consultants to the Task Force were:

David Z. Beckler
Richard N. Brandon
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Staff to the Task Force were:

Alexandra M. Field, Program Associate
Mark Schaefer, Senior Staff Associate

The Task Force also wishes to thank the many individuals within and outside of the Commission who commented on drafts of this report and provided numerous thoughtful suggestions. In particular, the Task Force appreciates the encouragement of David Hamburg, President of Carnegie Corporation of New York, throughout the development and review of this report. The Task Force would like to thank the various experts who reviewed drafts of this report and offered suggestions and comments. These include Frank Press, Robert White, Kenneth Shine, Richard Barke, Daryl Chubin, Barry Gold, Lionel Johns, Stephen Merrill, and Daniel Sarewitz.

The Task Force is grateful to Jeffrey D. Porro for writing and editorial contributions, to Jane Godshalk and Pamela Kulik for administrative assistance, and to Bonnie Bisol and Maxine Rockoff for guiding the production and distribution process. Jeannette Aspden provided the group with excellent editorial assistance throughout the publication process. The Task Force would also like to acknowledge the helpful suggestions made by David Z. Robinson and Jesse H. Ausubel.

EXECUTIVE SUMMARY

As for the Future, your task is not to foresee, but to enable it.
—Antoine de Saint-Exupéry, *The Wisdom of the Sands*

The end of the Cold War, the rise of other economically and scientifically powerful nations, and competition in the international economy present great opportunities for the United States to address societal needs: policymakers may now focus more attention on social and economic concerns and less on potential military conflicts. In the next decade and those that follow, the United States will confront critical public policy issues that are intimately connected with advances in science and technology. Policy decision making will require the integration of numerous considerations, including accepted scientific knowledge, scientific uncertainty, and conflicting political, ethical, and economic values. Policy issues will not be resolved by citizens, scientists, business executives, or government officials working alone; addressing them effectively will require the concerted efforts of all sectors of society. As Vannevar Bush wrote in his 1945 report to the President, *Science: The Endless Frontier*:

> Science, by itself, provides no panacea for individual, social, and economic ills. It can be effective in the national welfare only as a member of a team,

> whether the conditions be peace or war. But without scientific progress no amount of achievement in other directions can insure our health, prosperity, and security as a nation.[1]

The task force recognizes that many sectors of society contribute to the setting and achievement of long-term science and technology (S&T) goals, particularly the state governments and the industrial sector. Many policy areas with which state governments have had decades of experience, such as transportation, education, and agriculture, have come to the top of the national policy agenda. Nearly every state has a science and technology policy advisor or economic development program centered on science and technology, and it is through the states that many of our national S&T policies are implemented.[2] Even though the private sector is largely influenced by shorter term economic forces, it still employs the majority of scientists and engineers in the country and performs most of the nation's R&D. As a consequence, industry plays an important role in establishing and achieving long-term S&T goals.

Furthermore, we feel that it is important to recognize the role of international cooperation and development in government decision making in S&T. As discussed in a recent report by the Carnegie Commission, the distinction between "domestic" and "foreign" goals for science and technology is obsolete in the face of the explosion of global technology, information, capital, and people. If they are to be forward-thinking, our policies must now integrate national and international views.[3]

With this consideration in mind, our report focuses primarily on the role of the federal government in establishing and achieving long-term S&T goals. It also suggests some ways in which current problems can be managed and future issues can be identified and addressed. We discuss opportunities for opening the science policy process to a broader spectrum of society by creating and institutionalizing a forum for exchanging ideas. We also present mechanisms through which society and public officials can deal with the inevitable and continuing conflicts in goal-setting.

VOYAGES OF DISCOVERY

Basic scientific research is a voyage of discovery, sometimes reaching the expected objective, but often revealing unanticipated new information that leads, in turn, to new voyages. Some might say that setting long-range goals may harm basic researchers by overcentralizing and removing flexibility from the system. Long-range S&T goal-setting certainly should not hamper, but rather encourage, this freedom to discover. Furthermore, goal-setting should be a pluralistic, decentralized process.

The federal government is largely responsible for setting major goals and broad budget priorities between and among major disciplines (for example, biology and physics). It also plays a major role in setting priorities within disciplines (for example, particle and solid state physics), and must encourage the symbiotic combinations of differing fields (for example, biology and chemistry with respect to biotechnology products).

The relationships between scientific and technological advancement and government support are complex, and the stakes in these decisions are high, not just for scientists and engineers, but for society as a whole. Consequently, a better understanding of the process of articulating goals, both within and outside science, is vital.

THE CHOICE FOR AMERICA

We believe that America faces a clear choice. For too long, our science and technology policies, apart from support of basic research, have emphasized short-term solutions while neglecting longer-term objectives. If this emphasis continues, the problems we have encountered in recent years, such as erosion of the nation's industrial competitiveness and the difficulties of meeting increasingly challenging standards of environmental quality, could overwhelm promising opportunities for progress. However, we believe there is an alternative. The United States could base its S&T policies more firmly on long-range considerations and link these policies to societal goals through more comprehensive assessment of opportunities, costs, and benefits.

We emphasize the necessity for choice because there is nothing inevitable about the shape of the future: the policy decisions we make today will determine whether historic opportunities will be seized or squandered. American science could repeat its past successes: in the past three decades, American S&T has helped eradicate diseases, reverse the pollution of many of our rivers and lakes, reach the moon, launch the computer age, and spread the Green Revolution around the world. We may be able to achieve a new age of vitality and leadership in the world community. Or the problems of recent years—such as the loss of technological and commercial advantage to other nations, or our continuing dependence on foreign energy supplies—could prove irreversible. In short, the future is limited only by our ingenuity. As Frank Press, President of the National Academy of Sciences, said recently, "Without a vision of the future, there is no basis for choosing policies for science and technology that will be appropriate for the years ahead."[4]

This report seeks ways to improve the knowledge, understanding, and information available to the federal government on the long-term nature of the S&T enterprise as it relates to societal goals. As the government goes about the complex annual process of setting budget priorities and developing program plans for the S&T enterprise, it could use this knowledge, understanding, and information to ensure that both long- and short-term objectives are taken into account.

The report focuses on an interconnected set of ideas that, if implemented, would help accomplish this aim. The underlying theme of the set of recommendations is an effort to improve the capacity of the federal government to establish and achieve long-term S&T goals. At the core of our report is the recognition that there are significant efforts already under way within the federal government, but departments and agencies must be encouraged to direct more attention to long-term thinking. We describe the activities of several units of both the executive and legislative branches of government, recommend ways to strengthen their capabilities, and suggest mechanisms through which long-range, strategic planning can help federal departments and agencies fulfill their missions.

In addition to our recommendations directed to established governmental units, we have proposed the creation of a National Forum on Science and Technology Goals that would bring representatives of the science and technology community together with others from a broad set of fields who are interested in societal activities that have major S&T components. The Forum would work to identify ways in which science and technology can contribute to the definition and refinement of societal objectives and to their realization. Ultimately, it would try to articulate S&T goals, monitor efforts to achieve them, and maintain sustained support for particular objectives. The Forum would also define and develop criteria in support of dynamic goals such as the future needs of the several components of the science and technology base—basic research, generic technology, education and training, research facilities, and information dissemination, to name a few—in an effort to ensure their long-term health.

Several key considerations underlie our recommendation for a National Forum. The first is that a private forum must have long-term continuity in order to become an important contributor to federal policies. There are inherently long lead times associated not only with goals but also with the dynamics of major technological change. It is the mismatch between these realities and more immediate economic and political concerns that must be wrestled with. The second key consideration is the recognition that many organizations exist, both within and outside government, that do some long-term strategic planning. The Forum should make maximal use of these worthwhile efforts.

Furthermore, if the products of the Forum are to be useful, it must have strong linkages to the executive and legislative branches of the federal

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government as well as the state governments. Finally, a balanced and effective interaction is needed between the scientific and engineering communities and those representing a broad range of other societal interests.

Our report does not address the issue of setting specific societal goals, because we believe this is primarily a political process. We do list a broad set of societal goals to indicate the general directions toward which S&T should be applied. Most of our report is devoted to the *process* of establishing S&T goals; however, we do present some examples of S&T goals for illustrative purposes.

RECOMMENDATIONS

Although this report touches on a number of goal-related themes, our recommendations focus on a few key issues: improving our national capacity to define and revise long-term S&T goals; linking S&T programs and goals more closely and clearly to broader societal goals; and building more effective linkages between governments (especially the federal government) and other sectors of society in debating, articulating, and pursuing these goals while assessing progress toward their achievement. To this end, we present a set of interconnected recommendations. We believe that each recommendation, in itself, is useful and should be implemented; however, the recommendations have been designed to support and strengthen each other and should be viewed as a whole.

In developing recommendations in this report, we sought to identify mechanisms to bring the major sectors of society—government, industry, academia, nongovernmental organizations, and the public—together to examine ways in which science and technology can be focused on achieving the nation's long-term objectives. Centralization of planning is not the answer, as the failures of command economies have demonstrated. However, we badly need a focusing of national attention and resolve. We also need to ensure that we are taking full advantage of the knowledge resulting from our national research and development efforts as we work to achieve societal objectives. Bridging the gap between research and policymaking is essential, and the assessment process is an effective bridging mechanism that must be used more frequently in the future as policymakers work to devise strategies for achieving long-range goals.

Throughout our work, we have been mindful of the great diversity of processes that help define the direction of national policy. There is no simple way to promote systematic long-term thinking about policy directions. For this reason we devote our recommendations to a variety of mechanisms within and outside government to foster discussion and debate about potential long-term S&T goals and the means of achieving them.

■ **A nongovernmental National Forum on Science and Technology Goals should be established to facilitate the process of defining, debating, focusing, and articulating science and technology goals in the context of federal, national, and international goals, and to monitor the development and implementation of policies to achieve them.** The National Forum, as we envision it, would be responsible for undertaking several key activities (see Box 6 on p. 50). The Forum would convene individuals from industry, academia, nongovernmental organizations, and the interested public to explore and seek consensus on long-term S&T goals and the potential contribution of scientific and engineering advances to the achievement of societal goals.

The importance of the long-term goal-setting task is matched by the difficulty of carrying it out. For example, great diligence, fair-mindedness, and imagination would be needed to ensure that the Forum did not become either a vehicle for self-promotion by scientists and engineers or a venue for lodging grievances arising from technological change. The goal-setting process must involve individuals who have exhibited the ability to take a broad statesman-like view of complex issues.

We suggest two options for administering the Forum: the National Academies complex or a new, independent, nongovernmental organization. Regardless of the option chosen, we believe that the activities of the National Forum should be overseen by a Board of Directors responsible for selecting the members of the Forum's Council. The Council should be made up of representatives of a broad spectrum of our society who are appointed for fixed length, rotating terms. The Board should ensure that the Council is provided with the necessary institutional facilities, financial management, personnel, and other administrative backing to carry on the Forum's mission. We envision the Council as the leadership organization for the Forum.

■ **Congress should devote more explicit attention to long-term S&T goals in its budget, authorization, appropriation, and oversight procedures.** Congressional support is key to the long-term productivity of science and technology. Budget, authorization, appropriation, and oversight procedures are complex and highly decentralized, and there are opportunities to improve the ways in which Congress addresses S&T issues. We have not, however, focused too closely on these opportunities. The Committee on Science, Technology, and Congress of the Carnegie Commission will address these issues in an upcoming report.[5]

We believe that one of the most effective ways for Congress to consider S&T issues in the longer term would be for the House Committee on Science, Space, and Technology, which has responsibility for cross-cutting science policy considerations, to hold a series of hearings, on an annual or biennial basis, on long-term goals for science and technology. The purpose of these hearings would be to step back from the budget process and near-term political considerations and consider science and technology from the long-term perspective. However, we also believe that each legislative committee in the House and Senate that has jurisdiction over major segments of federal S&T activities should periodically, perhaps biennially, devote formal attention to more specific questions regarding long-term S&T goals in its area of responsibility.

Congressional committees could ask the appropriate federal agencies and a full spectrum of responsible nongovernmental interests for their views on long-term S&T goals, hold hearings, and issue reports embodying the committees' conclusions. As the proposed Forum matures and gains public confidence, the leadership of the Senate and the House of Representatives may wish to develop mechanisms to use the Forum's output throughout congressional S&T policymaking activities.

▪ **In order to provide Congress with the information, analysis, and advice necessary to make policy decisions in this area, the Office of Technology Assessment and other congressional support agencies should evaluate national efforts to establish and achieve long-term science and technology goals in the context of societal goals.** The support agencies should work with congressional committees to consider what kinds of analyses of long-term S&T goals would help inform their legislative agendas. OTA, in particular, should apply its well-tested assessment process to analyzing long-term S&T goals and the procedures by which federal agencies articulate and work toward their achievement. The Congressional Budget Office (CBO), although it has limited responsibilities for S&T policy, has considerable expertise in economic analysis, which is an essential component of the goal-setting process. CBO should put its expertise to use in evaluating economic considerations with respect to long-range science and technology policy.

More specifically, we believe that CBO and OTA should establish an ongoing coordinated activity designed to combine their strengths in analyzing economics and science and technology in order to evaluate goals and budget priorities for science and technology. Furthermore, because we believe that interactive linkages are the key to solving complicated problems, we suggest that OTA, with the cooperation of the other congressional support agencies, assist congressional committees and the congressional leadership in reviewing and evaluating the products of the Forum.

▪ **The Office of Science and Technology Policy (OSTP) and the Office of Management and Budget (OMB) within the Executive Office of the President should actively contribute to the establishment of federal science and technology goals and should monitor the progress of departments and agencies in attaining these goals.** Establishing long-term goals and communicating them to the federal agencies is a process that must be conducted separately from the annual budget process. With specific goals in mind, the agencies can create a budget that balances their vision of the future with the realities and constraints of the present.

OSTP and OMB should communicate long-term S&T goals to departments and agencies before the beginning of the budget cycle each year. In addition, both OSTP and OMB should work with these departments and agencies throughout their budget-planning processes to assure that long-term S&T goals are considered and advanced in their internal policy-planning activities.

OSTP should also monitor, critically evaluate, and report to the President and Congress on the progress of federal programs in achieving long-term S&T goals. In particular, OSTP should function as one liaison point between the National Forum and the Executive Branch. With OSTP leadership, the Federal Coordinating Council on Science, Engineering, and Technology (FCCSET) should extend its promising efforts in shaping long-term S&T goals involving more than one federal agency and emphasize the articulation of specific long-term goals through a more explicit planning process. Furthermore, the President's Council of Advisors for Science and Technology (PCAST) should play a more extensive role in guiding the goal-setting process within the Executive Office.

▪ **Federal departments and agencies should enhance their policymaking efforts, integrating considerations of long-term science and technology goals into annual budgeting and planning efforts.** Federal agencies should enhance their strategic planning capabilities and develop explicit long-term S&T goals in the context of broader national goals established by Congress and the President. In order to do this, open communication and cooperation among the senior R&D administrators of departments and agencies should be encouraged. These individuals should meet periodically to discuss longer-term objectives and ways in which their work might contribute to or compete with broader goals and stated policies. If this approach proved effective, it could become a more formal step in the policymaking process. Furthermore, federal agencies should be required to present publicly each year an analysis of how their planned activities relate to their long-range S&T programs. Resource requirements to support the achievement of these goals should be incorporated into annual budget plans.

In addition, we recommend that federal agencies support extramural policy studies that can aid in developing and evaluating long-term S&T goals. The National Science Foundation (NSF) should develop and monitor indicators of the health and productivity of the science and technology enterprise and its contributions to societal goals. NSF should expand its competitive grants program in science and technology policymaking and work to involve scientists and engineers in the S&T goal-setting process. NSF, in conjunction with OSTP and other federal agencies, should establish continuing programs to develop the information base necessary to monitor progress in achieving long-term S&T goals. Furthermore, the National Science Board should assume greater responsibility for devising approaches to setting long-term goals with respect to the S&T base.

1
LINKING SCIENCE AND TECHNOLOGY TO SOCIETAL GOALS

LOOKING TOWARD THE FUTURE

The end of the Cold War, the rise of other economically and scientifically powerful nations, and competition in the international economy present great opportunities to address societal needs as policymakers focus more attention on social and economic concerns and less on potential military conflicts. In the next decade and those that follow, the United States will confront critical public policy issues that are intimately connected with advances in science and technology.

Knowledge resulting from basic research must be exploited to improve the efficiency and effectiveness with which applied research and technological development are directed to societal goals. Policy decision making will require the integration of numerous considerations, including accepted scientific knowledge, scientific uncertainty, and conflicting political, ethical, and economic values. Policy questions will not be resolved by citizens, scientists, business executives, or government officials working alone; addressing them effectively will require the coordinated effort of all sectors of society. As President John F. Kennedy said, "Scientists alone can establish the objectives of their research, but society, in extending support for science, must take account of its own needs."

Our report focuses primarily on the role of the federal government in establishing and achieving long-term S&T goals; it also suggests some ways in which current problems can be managed and future issues can be anticipated, identified, and addressed. We look to opportunities to open up the science policy process to a broader spectrum of society through the institution of a forum for exchanging ideas. We also suggest ways in which society can deal with the inevitable and continuing conflicts in goal-setting and make reasoned judgments.

A CLEAR CHOICE

We believe that America faces a clear choice. For too long, our science and technology policies—apart, perhaps, from support of basic research—have emphasized short-term solutions while neglecting foresight and planning. If this emphasis continues, the problems we have encountered in recent years, such as erosion of the nation's industrial competitiveness and the difficulties of meeting increasingly challenging standards of environmental quality, could overwhelm promising opportunities for progress. We believe there is an alternative. The United States could base its S&T policies more firmly on long-range considerations and link these policies to societal goals through more comprehensive assessment of opportunities, costs, and benefits.

We emphasize the necessity for choice because there is nothing inevitable about the shape of the future: the policy decisions we make will determine whether the historic opportunities will be seized or squandered. American science could repeat its past successes: in the past three decades, American S&T has helped eradicate diseases, reverse the pollution of many of our rivers and lakes, reach the moon, launch the computer age, and spread the Green Revolution around the world. We may be able to achieve a new age of vitality and leadership in the world community. Or the problems of recent years—the loss of technological and commercial advantage to other nations, or our continuing dependence on foreign energy supplies—could prove irreversible. As Frank Press, President of the National Academy of Sciences, said recently, "Without a vision of the future, there is no basis for choosing policies for science and technology that will be appropriate for the years ahead."[6]

LONG-TERM S&T GOALS

Science and technology alone are seldom, if ever, sufficient to achieve societal goals, but they can play a major role when applied appropriately. The responsibility for pursuing long-term goals lies not only with the scientific and engineering communities, which must better demonstrate that their work is instrumental to the nation's goals,[7] but also with government, industry, academia, and the public, which all share an interest in the application of S&T and the achievement of societal goals. Furthermore, we recognize that even the most exciting and valuable S&T advances often have unintended consequences, and that goal-setting must be approached responsibly. We agree with the two principles that Bernadine Healy emphasized in her testimony before the Subcommittee on Science of the House Committee on Science, Space, and Technology regarding strategic planning processes:

> First, there will be no finality to the strategic planning. It must be an ongoing, living, breathing, growing process. This process must be capable of rapidly accommodating new scientific opportunity and responding to . . . emergencies. Second, the plan is not to be a rigid blueprint; rather, it will serve as a compass to guide us in our course of discovery.[8]

Finally, we believe that it is the process of articulating, refining, and achieving objectives that is the key to any success, and that without this process, goals can become rigid and outdated.

DEFINITIONS

An important first step in discussing long-term planning is agreeing on definitions. We derived a set of definitions for the purpose of clarifying some of the later discussions. Of primary importance to understanding this report, we have defined long-term goals as objectives that can be achieved over a period of 10 to 50 years or more, and near-term goals as objectives that can be achieved in less than 10 years. Priorities, on the other hand, refer to near-term resource allocations and policy objectives. Other definitions can be found in Box 1.

PAST ACCOMPLISHMENTS

A number of past accomplishments illustrate the importance of setting long-term S&T goals. In the early 1960s, President John F. Kennedy captured the minds of Americans with his famous announcement: "I believe this nation

Box 1. Definitions

In our view, **goals** are projected ends. To achieve them requires assembling and sustaining a manageable consensus on future objectives. The goal-setting process depends on focusing, sequencing, and committing resources to a vision of where we want to be some years in the future. We have defined **long-term goals** as objectives to be achieved over a period of 10 to 50 or more years, and **near-term goals** as objectives that can be achieved in less than 10 years. **Priorities**, on the other hand, refer to near-term resource allocations and policy objectives. **Budget priorities** attempt to order or position objectives within a given framework of externalities. Thus, establishing goals and assigning priorities are distinct but parallel processes. Annual or biennial budget priorities should be set in the context of relevant near-term and long-term goals.

It is useful to consider two major categories of long-term objectives: directed and dynamic.

- **Directed goals** aim to achieve particular, well-defined ends, such as mapping the human genome or executing a manned mission to Mars.
- **Dynamic goals** aim to achieve broader states or conditions that must be pursued continually or maintained once they have been achieved. Examples include optimal research facilities, an appropriate number of scientists and engineers in particular disciplines, and a viable, well-coordinated federal environmental R&D effort.

We have postulated a set of **societal goals**, those broader goals pursued for the improvement of society or some sector of society. This set includes several types of objectives:

- **International goals**, such as the worldwide eradication of smallpox, are those goals derived and pursued by a number of nations in concert.
- **National goals** are broad goals pursued mainly by one nation that derive from a domestic consensus on "what is good for the country." Securing and maintaining energy independence is an example of a possible national goal.
- **National S&T goals** are objectives of the nation's S&T enterprise; for example, the development of an operational commercial nuclear fusion reactor by the year 2040.
- **Federal goals** are more specific objectives, guided by the political process at the level of the federal government, that are established and achieved in order to attain national and international goals. An example is the goal of maintaining coal as a competitive energy source while meeting environmental, health, and safety requirements (an objective of the 1991/1992 National Energy Strategy).
- **Federal S&T goals** are objectives of federal research and development programs that are established to help attain federal goals. The demonstration of a low-CO_2-emitting coal-fired power plant by the Department of Energy is an example of a hypothetical federal S&T goal.

Finally, we have followed the recommendations of a 1988 report by the National Academy of Sciences (*Federal Science and Technology Budget Priorities: New Perspectives and Procedures*)[11] in broadly defining the **S&T base** to include not just personnel and facilities, but also the conduct of basic research and the development of generic or capability-enhancing technologies. These activities, in addition to their support of substantive areas of S&T that in turn support various societal goals, also directly advance the fundamental societal goal of increasing human knowledge and thus improving our quality of life.

should commit itself to achieving the goal, before the decade is out, of landing a man on the moon and returning him safely to earth." Largely because of the strategic political and military appeal of a contest with the Soviet Union, a societal goal that would not command the same attention in today's political and economic circumstances, an extraordinary national consensus was achieved and tremendous scientific and technological resources were marshalled to meet the challenge.

At the international level, the worldwide eradication of smallpox demonstrates how a long-term S&T goal can be established and achieved. In 1959, the Twelfth World Health Assembly resolved to pursue the goal of global smallpox eradication. In the early years, there was little progress, as natural and political problems took their toll and the difficulties of designing and maintaining coherent international programs became clear. However, in 1966 the World Health Organization committed itself fully to pursuing the final eradication of the disease. By May of 1980, the World Health Assembly was able to declare that smallpox had at last been eradicated.[9]

Long-term goals need not be limited to well-defined endpoints (directed goals) such as putting a man on the moon or eradicating smallpox, nor must the course to achieving them necessarily begin with a public pronouncement. Of special importance are the dynamic goals that aim to achieve broader states or conditions that must be pursued or maintained continually once they have been achieved. For many decades the United States has worked to build a strong and resilient academic research and engineering enterprise. From the early visions of Thomas Jefferson, to the "Endless Frontier" described by Vannevar Bush, to doubling the budget of the National Science Foundation in an effort aimed at preserving the gains of the past 200 years and assuring the future, the nation has worked to build and maintain an academic infrastructure that is second to none. Nevertheless, many feel that this infrastructure is showing signs of age and erosion. The dynamic goal remains, but because of periods of inattention, we may be farther from achieving it than we once were.

SCIENCE, TECHNOLOGY, AND SOCIETAL GOALS

It is not the purpose of this report to formulate societal goals nor to choose between them. However, we do discuss broad, general goals to which S&T can contribute. In Box 2 several such societal goals are grouped under four general headings: quality of life, health, human development, and knowledge; a resilient, sustainable, and competitive economy; environmental quality and sustainable use of natural resources; and personal, national, and international security.

Box 2. Examples of Major Societal Goals to Which Science and Technology Contribute

Quality of Life, Health, Human Development, and Knowledge

- Education and diffusion of knowledge
- Personal and public health and safety
- Personal development and self-realization
- Exploration and expansion of knowledge
- High standard of living
- Creation and maintenance of civic culture
- Cultural pluralism and community harmony
- Population stabilization

A Resilient, Sustainable, and Competitive Economy

- Economic growth
- Full employment and workforce training
- International competitiveness
- Modernized communications and transportation
- International cooperation and action

Environmental Quality and Sustainable Use of Natural Resources

- Worldwide sustainable development
- Resource exploration, extraction, conservation, and recycling
- Energy production and efficiency in use
- Environmental quality and protection
- Provisions for public recreation
- Maintenance and enhancement of productivity of the biosphere
- Maintenance of urban infrastructure
- Energy security and strategic materials

Personal, National, and International Security

- Personal security and social justice
- National and international security
- Individual freedom
- Worldwide human rights

In the past, for most of the areas of endeavor we have considered, the nation has been reasonably successful in establishing *near-term* S&T goals. However, insufficient consideration has been given to establishing *long-term* S&T goals and to linking them to societal goals in the context of changing social values and proliferating technical choices and opportunities. Yet even when goals are established, efforts to monitor progress in achieving them are often very limited. Long-term S&T goals are needed to provide a more meaningful context for defining near-term S&T goals and for better assessing the investment strategies required for their achievement.

By linking goals more closely with societal needs, necessary trade-offs between different federal, national, international, and other S&T goals—for example, between short-term economic gain and long-term environmental damage—can be made more carefully and systematically. At present, the mechanisms for making such trade-offs are haphazard, weak, and poorly defined and are frequently inconsistent among different areas of activity. For example, recent work has identified many areas where environmental improvement enhances rather than competes with economic development.[10] Creative use of technology can present new solutions that avoid a win–lose choice among equally valid goals and minimize the negative trade-offs.

An improved process of setting long-term S&T goals and incorporating them into societal goals will allow us to maintain a balance between continuity and flexibility in our future policies. The goal-setting process should never become so rigid that it cannot be altered by an unexpected breakthrough, by disappointing results that downgrade the priority of an area, by unforeseen advances in scientific knowledge, or by a sudden change in international or domestic politics. Linking S&T and societal goals is a dynamic, iterative, interactive, and adaptive process. Societal and S&T goals influence each other, and, once defined, they must be continually evaluated to determine if modifications are necessary. Not all long-term S&T goals are necessarily deducible from societal goals. Societal goals are heavily influenced by what is technically feasible and by the identification of new societal problems and challenges through research. There must be a continuous mutual adjustment between societal and S&T goals. Progress results from the skillful matching of societal problems that need solutions with scientific advances in search of applications. Thus, goal-setting works best when bottom-up and top-down strategies are pursued simultaneously, with wisely orchestrated interactions between the two.

In the long run, our ability to work in the applied areas of science and technology is dependent on the strength and quality of our S&T base—the human resources, facilities, and institutions that form the foundation of our research and development enterprise.[11] The supply of scientists and engineers for the applications areas, and the fundamental scientific knowledge on which they build, comes from the base (Box 3 lists the major components of the S&T base). Educating and training a scientist or engineer takes decades, from elementary school to postdoctoral training.[12] Equipping each successive generation of scientists and engineers with the latest research, design, and measurement tools is demanding and time-consuming. Research

Box 3. Major Components of the Science and Technology Base

- General science and mathematics education
- Scientific literacy of the public
- Higher education in science, engineering, and the social sciences
- Human resources (scientists, engineers, and technical personnel)
- Facilities and institutions
- Basic research and development of generic technology
- Diffusion of scientific and technical information

breakthroughs do not spring forth out of nowhere but are preceded by decades of gestation and the synthesis of knowledge from many sources and technical disciplines. Microelectronics, for example, grew out of solid state physics and chemistry, and biotechnology and genetic engineering evolved from molecular biology and biotechnology.

Linking S&T goals more closely to societal goals will also help to promote a strong and resilient S&T base. Without a solid and continually evolving base, the S&T enterprise cannot fulfill its role in advancing societal goals—that is, in enabling the future. This connection can work the other way, too. Strengthening the link between the S&T base and societal interests can help the public better understand how essential many activities of the S&T base—training scientists, modernizing research facilities, funding basic research, and so forth—are to the attainment of goals such as better health care, a cleaner environment, and economic security.

The executive and legislative branches formulate policies, initiate programs, and establish priorities for government activities, and they work to establish favorable conditions for nongovernmental activities as well. Normal political processes work reasonably well in this regard. However, we believe that all sectors of society should contribute to a longer-term examination of the ways that science and technology can contribute to the achievement of societal goals. We also believe that such mutual examination may, in the long run, be essential to public support for the S&T enterprise.

2
SETTING S&T GOALS

VOYAGES OF DISCOVERY

Basic scientific research is a voyage of discovery, sometimes reaching the expected objective, but often revealing unanticipated new information that leads, in turn, to new voyages. Some might say that setting long-range goals may harm basic researchers by overcentralizing and removing flexibility from the system. Long-range S&T goal-setting certainly should not hamper, but rather encourage, this freedom to discover. Furthermore, goal-setting should be a pluralistic, decentralized process.

The federal government is responsible for setting budget priorities between and among major disciplines (for example, biology and physics). It also plays a major role in setting priorities within disciplines (for example, particle physics and solid state physics), and must encourage the symbiotic combinations of differing fields (for example, biology and chemistry with respect to biotechnology products). Conflicts sometimes arise in the attempt to balance the researcher's freedom to discover, vital national needs, and the government's own responsibilities. A better understanding of the process of articulating goals, both within and outside science, is needed.

Goal-Setting: A Complex Task

Goal-setting for both science and technology is a complex—even daunting—task because the relationship between S&T goals and societal goals is neither self-evident nor transparent. It often requires difficult trade-offs among goals with different time horizons.

First, a balance between continuity and flexibility is essential. The S&T base must be built and nurtured over long periods of time. Sponsors must recognize the need to maintain support for fundamental research, because gaps in support for major components of the base can produce detrimental effects in later decades. At the same time, they must also be aware of the unpredictability of breakthroughs and must incorporate an element of resilience and flexibility to accommodate changes as they occur.

Second, it is reasonable for sponsors to expect results in a shorter time for directed research or development. Directed R&D is tied to specific expectations of applicability shared by practitioner and sponsor and is based upon the state of current knowledge.

Third, the amount of time required to produce usable results from each category of research and development may vary among and within fields according to the scope of the problem being addressed. For example, some energy production technologies may take as long as 50 years to achieve significant market penetration, while the dominant design of computer chips, or the market penetration of video cassette recorders, personal computers, and facsimile machines may occur in only a few years because of either improved materials or better architecture.

Fourth, the expectation of success in S&T efforts always includes an element of uncertainty. Prudent policy will often call for parallel pursuit of alternative approaches to the same goal. Finally, long-term S&T goals must be rationalized with other policy decisions, since they are intertwined with societal needs.[13]

Goals for Science, Goals for Technology

It should also be remembered that goals for science differ from goals for technology. Technological goals are usually linked to well-articulated social purposes. Scientific goals, on the other hand, are frequently multipurpose, exploratory, and primarily explanatory, contributing in multiple and often dimly anticipated ways to many different long-term societal goals. Thus, different policy frameworks are required for science and for technology—and, indeed, for technology-driven science, as compared with science driven by knowledge itself. Yet the innumerable feedbacks and cross-fertilization between science and technology preclude sharp differentiation between them because the relationship often evolves rapidly as new knowledge appears. Hence, both the societal goal-setting and S&T goal-setting processes are highly iterative and must be continually revisited by the scientific and policymaking communities in collaboration.

The Context of Goal-Setting

This report focuses on explicit goal-setting in many contexts. Sometimes there is a widely recognized problem that demands an urgent response, such as a military threat, a widespread disease, or a perceived loss of U.S. leadership in a critical field. A recent Carnegie Commission report noted, "American commercial manufacturing leadership has eroded in many sectors—particularly the automotive, electronic, and semiconductor industries—at the same time that growth in the world technology base and the globalization of industrial activities have increased international economic interdependence."[14] Such situations require a clear articulation of national goals and more aggressive policies to relate the science and technology enterprise to them.

Long-term goal-setting efforts may also be needed when existing programs and activities are not working effectively or are proceeding in different or even conflicting directions. For example, despite more than two decades of concern, the United States still lacks a coherent energy policy, and different branches of government often seem to be working at cross-purposes. In such situations it is necessary to seek a new consensus on a common set of long-term goals toward which all parties can work cooperatively.

A third context, and perhaps the most difficult to respond to, relates to situations in which important needs or problems are clearly seen by some (for example, some part of the S&T community or a public interest group) but are not universally recognized, and there is no consensus on the seriousness of the problem or on how to address it. The current question of how to respond to predictions of global climate change may be an example of this.

THE PROCESS OF SETTING S&T GOALS

Since goal-setting is a dynamic process, we believe that policymakers must analyze, identify, articulate, and ensure support for long-term S&T goals, while remaining alert to the contingencies and surprises that may emerge along the way toward achieving them. Long-term S&T goals have been established by various groups in the past. However, such efforts have been sporadic and inconsistent. Furthermore, goal-setting has rarely been followed up by a sufficient effort to achieve consensus in support of these goals and to monitor progress in achieving them.

Top-Down or Bottom-Up?

Policymakers must also be aware of the interrelationship between "bottom-up" and "top-down" approaches to setting goals. Basic research in most fields is largely initiated by individual scientists and engineers, with investigators setting their own agendas and seeking funds accordingly, and grantmaking or supporting institutions choosing among the requests. Much of the applied research and development, particularly that conducted by the private sector, is "top-down"— the agenda is determined by external criteria such as political, social, or economic utility. As the Organization for Economic Co-operation and Development recently concluded,

> [The] bottom-up approach has not been entirely satisfactory: while choices within a given area of science can be made on the basis of the quality of research teams or proposals, there is no 'scientific' criterion for ranking the importance of distinct fields. . . . But the top-down . . . approach has also proved impracticable, not simply because scientific progress and its applications are extremely hard to anticipate but also because the various fields of science do not advance independently of one another, and the most significant breakthroughs often occur at the interface of two or more fields. In its internal structure, science is an ever changing complex system.[15]

Stages of Goal-Setting

The process of establishing and achieving long-term S&T goals is rarely precise or orderly. At times it is opportunistic, at times reactive, and occasionally it is based on true foresight and inspiration. The desired outcome of the goal-setting process is not just the selection, definition, and articulation of a goal. It also involves the success of the entire process, including testing the goal through review mechanisms, building and maintaining a consensus of acceptance, and securing sustained support for achieving it.[16]

The process of goal-setting involves three major stages: articulation, introduction, and implementation (see Box 4). In carrying out these steps there are several fundamental considerations that deserve special emphasis as guiding principles for establishing long-term S&T goals:

Box 4. Establishing and Implementing Long-Term S&T Goals

Articulation

1. Define the problems and decide whether the establishment and articulation of long-term S&T goals would be a meaningful and constructive step in addressing them. The stakeholders and interested parties should be identified and their views on the pertinent issues given full consideration.

2. If establishment and articulation of a long-term S&T goal appears desirable, formulate the proposed goal and subject it to rigorous review to determine if it is realistic, economically feasible, and achievable. Assess the goal relative to other societal and S&T objectives and modify it if necessary.

3. Produce a statement clearly articulating the proposed long-term goal, including an explanation of the problem and why it is important, the need for actions over many years to address it, and the reasons for adopting the proposed goal and for supporting the measures needed to achieve it.

Introduction

4. Publicize and debate the proposed goal and consider modifications to strengthen it. Organize support for the proposed goal from stakeholders and others whose support is required for adoption and achievement.

5. Introduce the proposal into the pertinent approval processes of the organizations whose acceptance, approval, or support is required.

6. Support the proposal in the various review processes, with modification as necessary to secure approval.

Implementation

7. After initial approval, work to achieve and maintain support for the goal over time.

8. Create new institutions and/or change existing institutions to achieve the goal.

9. Reexamine the goal at suitable intervals for revalidation, modification, or complete revision.

- There should be a clear identification and understanding of the broader goals to which the S&T goals and activities are intended to contribute.
- Long-term S&T goals should be realistic in terms of the possibili-

ties and opportunities envisaged by the scientific and engineering communities.

- The mutually supporting functions of science and technology should be recognized: science creates new knowledge that enables new technologies, and new technologies, in turn, shape science.
- Any potential negative effects of proposed S&T goals should receive careful attention, and the necessary tradeoffs should be clearly identified (e.g., economic, social, and environmental costs and benefits, complementary non-S&T measures required, alternative ways of achieving the goals, and impacts on other goals).
- The time frame and costs required to achieve long-term goals must be defined and properly aligned with precursor near-term goals and available resources.
- Potential international implications of national S&T goals must be given full consideration.
- In order to achieve long-term goals, milestones and interim targets should be established to aid in monitoring and evaluating progress. Such a continuous process is likely to lead to periodic revision of both goals and the strategies to attain them. Without benchmarks, milestones, and explicit targets, it is very difficult to measure progress, to establish budget priorities, or to take advantage of experience.
- Finally, once long-term goals are approved, explicit provisions should be made for periodic reexamination of the goals and for modification and even abandonment of them if changed conditions warrant.

THE PLAYERS IN THE PROCESS

All major institutions in the science and technology communities—whether in federal or state government, industry, academia, or nongovernmental organizations—share the responsibility of ensuring long-term progress in their fields. Government and industry, which support research and development activities in approximately equal proportion, have particular responsibilities for strengthening the long-range vision of science and its applications and for ensuring enlightened policies and practices designed to optimize the contribution of science and technology to societal objectives. Furthermore, the U.S. S&T community shares responsibility with the S&T communities in other nations for articulating and working toward international objectives.

The Executive Branch

The executive branch, through its mission agencies, is responsible for directing the federal R&D enterprise toward broad societal objectives. However, the annual budget process dominates the policymaking process, and long-term goals receive relatively little attention. Also, potential goals that may involve several federal agencies are frequently overlooked because of the decentralization of the policy planning process.

Office of Management and Budget

Over the past thirty years, a set of coordinating mechanisms has been created within the Executive Office of the President to improve the direction of programs that cut across federal agencies. Although the primary responsibility of the Office of Management and Budget (OMB) is overseeing the annual budget process, a job that rarely results in systematic consideration of long-term, interagency concerns, OMB does participate in executive branch decisions to establish new goals or modify existing long-term ones.

Office of Science and Technology Policy

The original statute establishing the Office of Science and Technology Policy (OSTP), the National Science and Technology Policy, Organization, and Priorities Act of 1976, mandates a central role for the office in achieving national S&T goals. It states that

> the Congress declares that the United States shall adhere to a national policy for science and technology which includes. . . . The continuing development and implementation of strategies for determining and achieving the appropriate scope, level, direction and extent of scientific and technological efforts based upon a continuous appraisal of the role of science and technology in achieving goals and formulating policies of the United States and reflecting the views of State and local governments and representative public groups.[17]

OSTP was also expected to be a source of expert S&T advice close to the President and his senior staff, an institutional device to ensure expert involvement in both "science for policy" and "policy for science," and a framework for addressing S&T issues that cut across agency boundaries. OSTP has performed these several functions on a selective basis, addressing a limited menu of issues and initiatives, but it does consider some long-term goals in developing S&T policy, primarily through the activities of the Federal Coordinating Council on Science, Engineering, and Technology (FCCSET), with advice from the President's Council of Advisors for Science and Technology (PCAST). In recent years FCCSET has devoted considerable effort to articulating certain presidential initiatives known as "Grand Challenges" and to defining the role of S&T in meeting these challenges.

CONGRESS

Congress, like the executive branch, devotes most of its institutional energy to addressing issues specific to the mission of particular agencies. The annual budget process dominates the congressional agenda; hence, attention to long-term S&T goals is relatively limited. Congress, however, has had a long-standing interest in promoting the development of science policy in the context of longer range considerations.[18]

The Budget Committees

Within the legislative structure, the budget committees play a quasi-leadership role in policy development, parallel to OMB's role for the executive branch, shaping the spending priorities of different committees into a coherent package. Their charge to set broad spending priorities and leave line-item details to other committees tends to give them a longer-range perspective and a greater awareness of issues that transcend the jurisdiction of individual committees or agencies. Furthermore, since it is the responsibility of the budget committees to examine tax and spending priorities in light of overall economic conditions, they have an analytic basis for discussing long-term policy implications. The authorization and appropriations committees occasionally articulate long-term objectives. For example, environmental laws frequently require that the federal agencies work to achieve specific goals.

Congressional Support Agencies

Congress relies on analysis and advice from the four congressional support agencies: the Office of Technology Assessment (OTA), the Congressional Research Service (CRS), the General Accounting Office (GAO), and the Congressional Budget Office (CBO).[19] These agencies have varying degrees of S&T expertise. OTA is most active in this area, devoting all of its resources to science and technology policy issues. It undertakes studies and assessments of the impacts of technology or technological programs as well as alternative management programs. OTA also highlights areas where additional research or data collection is required for better assessments.

The States

The evolving role of state governments in developing, financing, and deploying science and technology has roots as far back as the mid-19th century. The 1940s debate over the role of governments in supporting science and technology drew the states even more directly into the process of S&T policymaking, as many of the societal concerns, such as agriculture, transportation, and education, that were being impacted by science and technology were considered the responsibility of state governments. Recently, many of these policy areas, with which state governments have had decades of experience, have come to the top of the national policy agenda. Nearly every state has a science and technology policy advisor or economic development program centered on science and technology, and it is through the states that many of our national S&T policies are implemented.[10] Any effort to establish long-term S&T goals should actively involve representatives of state governments.

Academia

The academic sector provides unmatched reservoirs of the talents required to suggest long-term S&T goals, analyze them, and help achieve them. At present, with tensions running high about funding and other issues, there is little cooperative effort devoted to effective goal-setting by universities, government, and other sectors. Nevertheless, one institution, the Government–University–Industry Research Roundtable (GUIRR) in the National Academies complex, has helped explore the research community's goals, roles, and responsibilities.

Industry

Industry employs the majority of scientists and engineers in the country and performs most of the national R&D. Industry, almost of necessity, takes a very short-term perspective in most of its activities. The technological goals of the private sector are strongly influenced by macroeconomic forces, ranging from tax policy to interest rates to consumer preference, as well as by other forces, such as regulation and the court system. The primary concern of individual firms is thus not long-term national S&T goal-setting, nor linking such S&T goals into the network of broader societal goals. However, industrial executives and R&D managers are an important resource that should be tapped during the process of attempting to articulate long-term national S&T objectives.

Nongovernmental Organizations

Scientists and engineers from the public as well as private sectors have formed their own organizations to facilitate direct political participation and to engage in forecasting the impacts of developments in S&T. Increasingly, these nongovernmental organizations have sought to create committees or sponsor studies on the subject of the interrelationship between science and technology and societal needs. Professional societies and trade associations like the American Institute of Aeronautics and Astronautics, the Ecological Society of America, and the Institute of Electrical and Electronic Engineers have devoted attention to long-term S&T goals in their areas of interest. Given their ties to the more active members of their professional communities, these groups are in an ideal position to evaluate research needs in the context of societal objectives and to discuss and develop long-term goals. This would bring diverse new perspectives, including those of individuals in the industrial sector, into the goal-setting process. Environmental policy-oriented nongovernmental organizations such as Resources for the Future, the World Resource Institute, and the World Wildlife Fund have established extensive networks with individuals and organizations within the public and private sectors. Groups such as these can play an important role in the process of articulating long-term S&T-related goals.[11]

The premier nongovernmental organization affecting S&T policy is the National Academies complex, which includes the National Academy of Sciences, the Institute of Medicine, the National Academy of Engineering, and the National Research Council. Most of the funding for the Academies complex is derived from governmental contracts for studies ranging from narrow technical assessments to broad policy reviews. The expert panels operating under the umbrella of the National Research Council provide a widely accepted vehicle for ascertaining the mainstream scientific consensus on technological issues and on public policy issues of high technological content.

International Players

Formally organized intergovernmental activities in science and technology, such as those sponsored by agencies of the United Nations system, have proven to be an effective mechanism for articulating and achieving certain long-term international goals. The eradication of smallpox, for instance, could not have been accomplished without a tightly integrated, highly professional, and robustly cooperative effort in which the United States was a committed participant. Establishing and achieving this goal was facilitated by clear analysis and a durable consensus on the importance of attaining global health objectives through cooperative international efforts; the requisite expertise and resources could then be brought to bear.

3
THE NEED FOR LONG-TERM GOALS: SELECTED ILLUSTRATIONS

It is not the purpose of this report to argue in favor of any particular long-term S&T goal, but to suggest ways of improving the *process* of setting long-term S&T goals. We have identified twelve key policy areas (see Box 5), and have chosen four of these to illustrate the arguments made and concepts introduced in earlier sections; they are therefore only heuristic, and *should not be construed as specific policy recommendations.*

ENVIRONMENT AND NATURAL RESOURCES

Public interest in and support for efforts to maintain and improve environmental quality have risen steadily over the past two decades. This concern arises from societal interest in protecting public health and promoting the conservation of key ecosystems needed to sustain the productivity of the bioof them may prove indispensible to advances in agricultural productivity, medicine, and industry.

In a world of sovereign nations, political institutions are only just beginning to struggle with environmental issues, and science is only just beginning to come to grips with the complex interactions between the economy, the environment, and the production and consumption of energy.[22] Concrete political action is frequently inhibited by scientific uncertainties and the resulting controversies over the urgency of immediate action. Some countries have worked actively to develop long-range environmental objectives and programs to achieve them. The Dutch government, for example, has devoted considerable effort to a long-range environmental policy plan.[23]

Science and technology contribute to efforts to address global environmental problems in three general ways. First, multidisciplinary research can elucidate and help to anticipate changes in the natural environment. It can do this through study of the earth's climate and hydrologic systems, biogeochemical dynamics, ecological systems and their dynamics, the earth's past history, and all the complex interactions between human activity and natural systems, including the determinants of population growth, energy demand and supply, changes in land use, and industrial production and its resource demands and residues. These are some of the objectives of the federal Global Change Research Program, a multiagency research program initiated in 1990 and coordinated by FCCSET within OSTP.

Second, progress in science is indispensable in the detection and monitoring of pollution, which, as we have indicated earlier, is less and less amenable to detection by the unaided human senses. It is also essential for quantifying and understanding the effects of environmental change on people, which in turn is essential for setting priorities for regulation and control of environmental impact. We can no longer afford to do at once everything that might be desirable or beneficial. We therefore increasingly need a more rational means of selecting priorities than the latest newspaper headline or an attention-getting environmental incident.

Third, new industrial and agricultural technologies—information technologies, biotechnologies, materials technologies, energy generation technologies and advances in end-use efficiency in the consumption of energy, transportation and communication technologies—can lead to dramatic reductions over time in the amount of environmental deterioration per unit of output of goods and other human amenities. Furthermore, reduction in environmental impact per unit of output often leads to improvement in labor and productivity as well. To permit sustainable economic growth and welfare improvement, however, requires the continual, and indeed accelerating, production of new knowledge and its rapid diffusion and application in every industrial sector and in the public infrastructure. But constant iteration be-

Box 5. Policy Areas That Would Benefit from the Articulation of Long-Term S&T Goals

- Environment and natural resources
- Health and social welfare
- Economic performance
- Food production and distribution
- Energy supply and utilization
- National and international security
- Basic and continuing education
- Transportation
- Public infrastructure
- Telecommunications and information management
- Exploration and expansion of knowledge
- S&T base (including facilities and personnel)

sphere for human sustenance in the future, and from the desire to enjoy the quality of life provided by contact with relatively unspoiled nature. Legislation directed at the protection of the environment and natural resources has proliferated rapidly, often expressing goals that outrun the current capacity of science and technology. At first, national objectives focused on the local environment and on the more visible forms of degradation such as smoke, visibly polluted water, and unsightly landfills. However, this concern rapidly expanded to embrace regional and eventually global environmental deterioration, as well as more subtle forms of invisible pollution that could be detected only with sensitive measuring instruments.

With the aid of increasingly sophisticated scientific and technological tools, substantial progress was made in reducing both the visible and some of the less visible forms of pollution, such as the particulate loading of the atmosphere, the contamination of food and water by pesticides, and dangerous waste sites containing toxic chemicals. Despite much progress, growth in population and economic activity continues to cause degradation of the natural resource base, including soils, water resources, fisheries, forests, and the atmosphere. Although science and technology have so far helped to minimize the depletion of reserves of mineral resources, or have led to the development of substitutes or better recycling techniques, concern remains about the future availability of so-called nonrenewable resources.

More recently, environmental issues that are truly global have risen to the top of the public policy agenda. These include stratospheric ozone depletion, the buildup of greenhouse gases, and loss of biodiversity due to the accelerated extinction of species through the destruction of their habitats. These threatened species not only enrich our cultural life, but some tween scientific findings, the social agenda, and the scientific research agenda are required to make this happen.

There are a number of successful historical examples of goal-setting in the environment and natural resources area, leading to establishment of linked S&T goals. A recent example is the goal in the Montreal protocol of total phaseout of CFCs, halons, and carbon tetrachloride production by the year 2000 in industrialized countries and by the year 2010 in developing countries. This international treaty has already resulted in aggressive action by industry worldwide to introduce economically and environmentally acceptable substitutes for CFCs. Some of the development work in industry and elsewhere has anticipated the actual formalization of targets. The task force believes that similar goal-setting is possible and desirable in other areas of environment and natural resources policy. While targets and dates have a certain amount of public appeal, which can help focus effort, they may carry an implication that, once achieved, the work has been done and efforts can thereafter be relaxed.

Scientific and professional societies can do much to establish goals for progress in their own disciplines that are tied to long-term societal goals. Some efforts have been made over the last two decades, but the goals should be clearly articulated and updated periodically to account for achievements in other disciplines.

The Ecological Society of America recently undertook an organized effort to devise ecological research goals and priorities in the context of national and international environmental objectives. According to its authors, the Sustainable Biosphere Initiative (SBI) "is intended as a call-to-arms for all ecologists, but it also will serve as a means to communicate with individuals or other disciplines with whom ecologists must join forces to address our common predicament."[24] The SBI presents a vision for the future of the ecological sciences and sets priorities for the acquisition of ecological knowledge, communication of this knowledge to the public and decision makers, and incorporation of this knowledge into policy and management decisions in government, industry, and other institutions. SBI has already met with success, moving forward from the concept stage into an active and growing project office. This initiative on the part of ecologists to think about and plan their future activities in the context of national needs and the activities of other scientific disciplines serves as a useful model for other scientific and engineering organizations.

Another forward-looking effort is under way in the federal government. The new Future Studies group within the Office of Policy Planning and Evaluation of the Environmental Protection Agency is charged with identifying and examining alternative futures of society, exploring the environmental impacts and implications of these futures, including these implications for research needs, and examining policy options for risk reduction and management for the different scenarios. Furthermore, to ensure access to a full range of perspectives, the group is seeking the views of a large number of forward-thinking experts in both the public and private sector. We feel that this program should be closely monitored as a potential model for parallel studies by other agencies.

HEALTH AND SOCIAL WELFARE

The health of the American people, as judged by life expectancy, has been improving since the turn of the century. Initial improvements in longevity primarily reflected diminished mortality from infections and were largely attributable to improvements in sanitation and nutrition and to the development of effective vaccines. Sulfonamides, penicillin, and other antibiotics contributed to a further decrease in death rates. In recent years, increases in life expectancy have resulted primarily from reductions in cardiovascular death rates from stroke and coronary artery disease. These improvements reflect control of hypertension, a decrease in the prevalence of smoking, decreases in the intake of fats and cholesterol, better weight control, and healthier lifestyles. There have also been substantial reductions in death rates from certain types of cancer, owing to improvements in surgery, radiation, and chemotherapy. Unfortunately, increases in lung cancer due to smoking have approximately canceled out the successes with other forms of cancer.

The ability to intercede successfully in an ever-increasing array of diseases results in no small part from our success in pursuing long-term national and S&T goals that are often implicit in the public support of biomedical research, which is administered primarily through the National Institutes of Health (NIH). Since the early 1950s, the NIH budget has shown steady real growth, increasing by more than 40 percent in the 1980s. Historically, this growth has been an expression of societal interest in improving personal and public health.[25] In the last decade, support for life science research has also begun to reflect national interest in U.S. economic competitiveness in the global biotechnology industry (the products of biotechnology, of course, have applications in agriculture and animal husbandry as well as in the diagnosis and cure of disease). The investment in the foundation of basic biomedical knowledge has been the key to our ability to plan systematic attacks on newly identified health problems such as AIDS.

However, despite U.S. leadership in virtually every aspect of biomedical science, its clinical applications, and the underlying basic science, there is growing dissatisfaction in the country with our inability to deliver its benefits to all our people, and with the rapid growth of the burden placed on the

U.S. economy by health care costs, a burden not borne by many other countries with which we compete in the world marketplace.

There is a mismatch between the long-term societal goals necessary for our society's well-being in the 21st century and many of the present scientific goals of the research. The implications for biomedical research of a new social goal of cost-effective and equitable health care delivery to the entire U.S. population have not yet been carefully analyzed. Undoubtedly, one implication is much more emphasis on the understanding of social and behavioral factors in health status, and the methods by which individuals can be persuaded to take a greater responsibility for their own health. Another may be intensification of the search for preventive technologies.

Recently, NIH, under its director, Bernadine Healy, has put considerable effort into developing a strategic plan for the institutes. The goal of the plan is to develop a vision that transcends immediate concerns and ensures the future strength and vigor of biomedical research. In developing its plan, NIH has been aware of the importance of flexibility, and has sought to develop a strategy that neither imposes rigid timetables nor relies on predictions about the future. Instead, it creates a framework for cohesive thinking and for successful preparation for the future. Furthermore, NIH has sought active participation of the extended biomedical community as well as the public in shaping and implementing the plan. The process is only in its early stages, but it is a bold step forward, consistent with the themes of this report.[16]

This section of our report is entitled "Health and Welfare" rather than just "Health." This is deliberately intended to suggest the intimate relationship that exists between health and social welfare, and the need for this relationship to be better incorporated into the long-range research goals that include health.

ECONOMIC PERFORMANCE

"Economic performance" covers a wide variety of important societal goals and associated policy areas. The Carnegie Commission recently released a report on the role of science and technology in enhancing economic performance.[17] Long-term goals in these areas are mostly what we have defined as the dynamic or continuing type, such as maintaining a good rate of per capita economic growth, a strong international competitive position, and employment security. Although the goals tend to be formulated in national terms, they are actually international in nature because of the growing interdependencies in the world economy. U.S. economic performance depends to an increasing degree on the performance of the world economy, including the growth of markets in the Third World.

Economic performance goals vary widely in the degree to which S&T can be expected to contribute to their realization. The overall performance of the economy, in both the near and long term, is critically dependent on fiscal and monetary policies and on initiatives and decisions of our industry and business leaders and their foreign competitors, many of which concern the creation, acquisition, and the deployment of technology. In the words of a 1987 report for NSF by the National Governors' Association, "one area of consensus is that U.S. investments in research and education will be critical in the long-term as the United States seeks to maintain and improve its competitive position in the world economy."[28]

Goal-Setting in the Private Sector

Establishing specific directed goals in science and technology to enhance economic performance is, in the U.S. economic system, a major function of individuals and organizations in the private sector. This goal-setting necessarily takes place in the context of decisions on overall business strategy, in which the cost and prospective benefits of the S&T activities are only two of many factors. The many uncertainties in forecasting future economic, market, regulatory, and competitive positions tend to force an emphasis on near-term goals and to militate against major commitments to long-term goals (at least in the U.S., though this is much less true in Germany and Japan).

Federal S&T Goals and Economic Performance

Long-term federal S&T goals linked to national goals can make significant contributions to the nation's economic performance. For example, during World War II, significant funds were devoted to the development of radar and computational capabilities. The outcome of pursuing these goals has had a profound impact on the economy in the ensuing decades. The commitment to the advancement of aeronautical science and technology embodied in NASA's programs reflects the acceptance since the establishment of the National Advisory Council for Aeronautics (NACA) in 1915 of a national "dynamic" goal of continuous advancement of aeronautical S&T for the benefit of U.S. civil as well as military aviation. Similarly, federal support of the development of nuclear energy was designed to support the development of an important new source of energy and to promote the development of a strong and competitive nuclear industry. Most recently, there have been a number of initiatives within the federal government, most notably the legislated Critical Technologies Institute, to identify emerging critical technologies and to support their development.

We believe that careful further study is needed to identify S&T areas of special significance for economic performance in which establishing long-term federal goals is desirable. What areas of S&T warrant the establishment of major federal undertakings comparable to those in aeronautics and nuclear energy? What should our long-term S&T goals in these areas be? Are there significant gaps in the range of generic technology programs now supported by government and private consortia? Do the existing programs need more clearly defined long-term goals?

Strengthening the U.S. Manufacturing Base

Finally, we note that one area that appears to deserve special attention is manufacturing technologies that can make U.S. industries more efficient and thus more competitive in world markets. The new high-technology industries require not only large research and development investments but also massive capital investment in plant facilities. To sustain profits, these industries must use superior process technologies and flexible manufacturing systems that involve high fixed costs and rapid innovation cycles. The U.S. manufacturing base is weaker than its foreign competitors' in the automobile, semiconductor, and consumer electronics industries, and stronger in the aerospace, computer, chemical, and pharmaceutical industries. In general, the U.S. manufacturing base requires continued strengthening through the modernization of facilities and the injection of new technologies, capital, and trained people. This is in large part ensured by the workings of the marketplace, but federal and state economic policies also have a role to play.

To strengthen the U.S. manufacturing base, long-term S&T goals—especially federal goals—must emphasize creation of generic technologies, diffusion of knowledge throughout the U.S. industrial economy, and support for basic research in universities and industry. Examples of generic or capability-enhancing technologies include computer-based tools for automated design, nondestructive test methods, software engineering tools, materials characterization and synthesis, and semiconductor manufacturing processes.

THE S&T BASE

The task force agrees with the 1988 study by the National Academy of Sciences[29] in its recognition that the maintenance of a robust, resilient S&T

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base is a *sine qua non* if science and technology are to fulfill their potential for contributing to societal goals. A good deal of the knowledge needed for achieving societal goals is not acquired with these goals explicitly in mind; rather, it is the result of efforts to answer questions posed within science.

Configuration of the S&T Base

The S&T base should be configured to foster individual creativity, to permit the organization of large-scale team efforts when necessary, and to focus attention on practical applications and generic technology development as well as on basic research. Its various elements in government, universities, and industry must be linked by effective communications networks and underpinned by healthy facilities and institutions. It should also provide for continual regeneration and revitalization through a constant supply of well-trained younger scientists, engineers, and technicians. Only with such a robust, resilient S&T base can both the predictable advances and the unexpected breakthroughs in science and engineering be integrated effectively into organized efforts to achieve national and societal goals.

A fundamental question that the nation must address is the size and general composition of the S&T base that should be maintained in federal agencies, universities, nonprofit organizations, and industry. Should our goal be to maintain or expand the present base or to find the least damaging ways of contracting it to conform to probable future budget constraints? Should our goal be equalization of geographic distribution or concentration of resources in a more limited number of centers of excellence?

Science, Engineering, and Technical Personnel

Specific long-term goals are essential with respect to scientific, engineering, and technical personnel. Balancing the demographics of supply with realistic forecasts of demand is a major challenge. Recent studies indicate that the United States is lagging behind other nations in K–12 science and mathematics education. If this is allowed to continue, not only will the result be a scientifically illiterate public, but the number of young scientists and engineers entering the pipeline could be affected.[30]

Long-term S&T goals are also needed with respect to R&D facilities and institutions. For example, the absence of clearly established policies and long-term goals with respect to the maintenance and modernization of research facilities in our universities has led to a confused situation in which universities are increasingly turning to direct political action to secure funding through congressional earmarking.

Basic Science and Generic Technology

In the case of basic science and generic technology development, where applications to specific societal goals are not clearly foreseen, the establishment of long-term goals may not be necessary or helpful—the unfettered, curiosity-driven imaginations of scientists and engineers may best be left alone.

But long-term goals may be important in at least two situations. When specialists conclude that significantly greater progress can be made through the coordinated efforts of many scientists, a clear articulation of the long-term goals towards which all should work may be crucial. The human genome project may be an example. Establishment of long-term goals in basic science may also be necessary in fields where research facilities are limited or very costly; planetary exploration and high energy physics are examples. If the long-term S&T goal is only to increase knowledge, goal-setting may be left to the scientific and technical specialists. However, if other S&T or national goals become significant factors, a broader community must be involved in the process.

THE ROLE OF A NATIONAL FORUM

We have presented these case studies merely to illustrate the kinds of issues that a National Forum on Science and Technology Goals could address; they are neither recommendations nor examples of the products of a Forum process. As these four illustrations suggest, the policymaking process would benefit greatly from a broader discussion of future directions for science and technology and a clear articulation of long-term goals and the resources required to achieve them.

4
RECOMMENDATIONS

While this report touches on a number of goal-related themes, our recommendations will focus on several key issues: improving our national capacity to define and revise long-term S&T goals, linking S&T programs and goals more closely and clearly to broader societal goals, and building more effective linkages between governments (especially the federal government) and other sectors of society in debating, articulating, and pursuing these goals while assessing progress toward their achievement. To this end, we have put forth a set of interconnected recommendations. We believe that each recommendation, in itself, is useful and should be implemented; however, the set of recommendations should be viewed as a whole, as they have been designed to support and strengthen each other.

In developing our recommendations, we have sought to identify mechanisms to bring the major sectors of society—government, industry, academia, nongovernmental organizations, and the public—together to examine ways in which science and technology can be focused on achieving the nation's long-term objectives. Centralization of planning is not the answer, as the failures of the command economies have demonstrated. However, we badly need a focusing of national attention and resolve.

Throughout our work, we have been mindful of the great diversity of processes that help define the direction of national policy. There is no simple way to promote systematic long-term thinking about policy directions. For this reason we devote our recommendations to a variety of mechanisms within and outside government to foster discussion and debate of potential long-term goals and the means of achieving them. Within the federal government, we propose mechanisms for institutionalizing long-term S&T goal-setting as an inherent part of the congressional and executive branch S&T policymaking processes. Outside government, a common theme of our recommendations is the involvement of all sectors of society and the citizenry in an ongoing dialogue on future directions for science and technology in the context of societal needs and aspirations. We believe that the National Forum on Science and Technology Goals, as described below, would be a useful mechanism for achieving consensus among various sectors of society on future directions for science and technology.

NATIONAL FORUM ON SCIENCE AND TECHNOLOGY GOALS

▪ **A nongovernmental National Forum on Science and Technology Goals should be established to facilitate the process of defining, debating, focusing, and articulating science and technology goals in the context of federal, national, and international goals, and to monitor the development and implementation of policies to achieve them.** The National Forum, as we envision it, would be responsible for undertaking several key activities (see Box 6). The Forum would convene individuals from industry, academia, nongovernmental organizations, and the interested public to explore and seek consensus on long-term S&T goals and the potential contribution of scientific and engineering advances to societal goals.

Because of the difficulties of defining societal goals, it may be desirable to consider a preliminary function for the Forum to be the identification and assessment of the explicit and implicit long-range objectives and goals of federal research and development as revealed by annual budgets. This would show which R&D efforts lack clear long-range objectives and which are based on faulty assumptions; it would point out specific requirements for long-term goal-setting in order to resolve ambiguities and provide better direction.

We further believe that the Forum should focus its attention ini-

Box 6. Key Activities of a Proposed National Forum on Science and Technology Goals

- Assemble a broad-based and diverse group of individuals who are both critical and innovative, and who can examine societal goals and the ways in which science and technology can best contribute to their achievement.

- Conduct or sponsor discussions with individuals representing a diversity of perspectives on future directions for our nation and the role of science and technology in meeting alternative societal goals. Conduct or sponsor analytic and background studies. Consider the tradeoffs involved in working toward particular goals, including competition for funds and personnel, and the possibility of negative impacts on other goals.

- Articulate and propose specific long-term S&T goals in both national and international contexts, and identify milestones in achieving them.

- Encourage efforts by the media to improve public understanding of and participation in the process of establishing S&T goals.

- Identify and evaluate promising breakthroughs in basic research and new technologies to ensure that they are taken into full account in the formulation of societal and S&T goals.

- Communicate the products of the Forum's work to those who directly influence the direction of science and technology policy, including the executive and legislative branches of the federal government, key officials in all state governments, and key executives and research directors in industry and universities.

- Monitor and report on progress and problems in achieving long-range S&T goals and on the contributions of S&T to societal goals.

- Periodically examine S&T goals in the context of new developments in science and technology or changing social, economic, or political concerns.

tially on goals in two or three policy areas (taking into account the health of the S&T base in achieving these goals). We recognize that certain topics, particularly those dealing with issues of national and international security, do not lend themselves easily to an open forum process. Fortunately, there are already mechanisms in place that focus on long-term issues in the security area. The Forum will be able to consider some of these issues and work with appropriate organizations to bring the benefit of a forum process to the defense R&D policy area.

It would be essential for the Forum, as we envision it, to have numerous links to the federal government, links designed to enhance communication without placing the Forum within the official hierarchy. This would put the Forum in an ideal position to critique the budgets of departments and agencies periodically, perhaps annually, focusing on the extent to which they consider long-term goals and act to advance them. Another objective of the Forum would be to define and develop criteria in support of dynamic goals such as the future needs of the several components of the science and technology base—basic research, education and training, and information dissemination, to name a few—in an effort to ensure their long-term health. This is especially important because the S&T base is the foundation of future scientific and engineering advances.

The importance of the long-term goal-setting task is matched by the difficulty of carrying it out. For example, great diligence, fair-mindedness, and imagination would be needed to ensure that the Forum did not become either a vehicle for self-promotion by scientists and engineers or a venue for lodging grievances arising from technological change. Many institutions could contribute directly to the Forum's activities. The National Academies complex, the congressional Office of Technology Assessment, the White House Office of Science and Technology Policy, and the Smithsonian Institution (because of its extensive activities pertaining to the public understanding of S&T issues) are among the specialized organizations that are clearly central to the long-term S&T planning process. No single agency has all the characteristics and capabilities required. Moreover, regardless of the final form or location of the Forum, it will require congressional and executive support. We have considered two possible approaches to organizing a National Forum.

Option 1. The National Academies complex may be the best place to establish and administer a National Forum, with the active participation of many other organizations. The Academies complex (including the National Academy of Sciences, the National Academy of Engineering, the Institute of Medicine, and the National Research Council) has a well-respected network of science and technology leaders from academia, industry, and government, proven support staff and operational capabilities, and an ability to obtain and combine satisfactorily both public and private funding.

One of the great advantages of the Academies complex is that it is an existing organization with many of the needed assets—administration, staff, and committee panel structure—already in place. Furthermore, the Academies complex has often played the type of catalyzing role envisioned here. A four-year pilot operation might be conducted to determine the feasibility of the forum concept; this would provide the experience for designing an alternative organization if a different structure proved to be desirable. A possible disadvantage of using the Academies complex is its image as an S&T-focused organization with weak links to the non-S&T communities concerned with national goals, although it has frequently engaged individuals from those communities in carrying out its studies.

Option 2. An alternative would require establishing *de novo* an independent, nongovernmental organization. A new nongovernmental organization would have the benefit (as well as the shortcoming) of operating independently of an existing institution and could be custom-designed to carry out the functions of the Forum. This arrangement would require developing new administrative and program staffing capabilities, which would be more difficult than building on those of an existing organization. As with the first option, a four-year pilot program might be appropriate.

Deciding where to site the National Forum requires a judgment about where, among a number of likely organizations outside government, three critical requirements appear most robust: (a) deep and well-tested analytical resources, (b) ability to get and hold government's attention, and (c) demonstrable capacity for integrated scientific, technological, and environmental assessment.

Given these demanding requirements, we are strongly drawn to siting the Forum process within the National Academy of Sciences complex. Moreover, we prefer the Academy because it has demonstrated, in recent years, striking flexibility and initiative in its organization and process. Among such initiatives, four are notably related to the long-range goals agenda: the Government–University–Industry Research Roundtable; the Committee on Science, Engineering, and Public Policy; the Mathematical Sciences Education Board; and the Board on Science, Technology, and Economic Policy. In sum, the Academies complex brings together strong research and analytic capacity with responsible quality control practices plus the institutional accountability deriving from the special governmental relationship stipulated in its 1863 congressional charter. This convergence of organizational assets appears well-suited to the difficult and complex task of tackling long-range goals.

Although we believe that the Academies complex is best suited to organize and launch the Forum process, we do not have in mind a closed enterprise; nor, we are certain, would the Academies leadership put their organization in such a position. There should be in a workable Forum "system" much sharing of roles and functions with responsive institutional partners—for example, with an entity such as the National Science Board from time to time, or with a cluster of policy studies centers located in university settings, as well as with nongovernmental organizations with substantial and contrasting informational and advocacy strengths and different perspectives.

Regardless of the organizational option chosen, we expect that funding for the Forum would eventually originate from a variety of public and private sources. Furthermore, the activities of the National Forum should be overseen by a Board of Directors. In the case of option 1, the Board might include the Presidents of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine, and other national leaders in the public policy arena. In the case of option 2, the Board of Directors might include the President of the National Academy of Sciences, the Director of the White House Office of Science and Technology Policy, a representative of Congress chosen by the congressional leadership (for example, the Director of the Office of Technology Assessment), and the Secretary of the Smithsonian Institution.

In either case, the Board of Directors would be responsible for selecting the members of the Forum's Council, a group made up of representatives of a broad spectrum of our society appointed for fixed-length, rotating terms. The Board should ensure that the Council is provided with the necessary institutional facilities, financial management, personnel, and other administrative backing to carry out the Forum's mission. We envision the Council as the leadership organization for the Forum. The Council should meet regularly with the Board to report on its activities and to seek advice on future activities. In addition, the Council should take full advantage of such National Research Council groups as the Government–University–Industry Research Roundtable, the new Board on Science, Technology, and Economic Policy, and the several international boards and committees that operate through NRC sponsorship.

If the activities of the Forum are to be worthwhile, its products must be welcomed and used by senior officials in the executive and legislative branches of the federal government. To this end, it would be desirable to establish ties directly with offices that would act as focal points for receiving, requesting, and responding to the products of the Forum. In the executive branch, we feel that OSTP and OMB should serve as focal points in the Executive Office of the President. The Forum should also maintain close contact with individual executive branch agencies responsible for particular policy issues.

In the legislative branch, we feel that the congressional committees with major S&T responsibilities, such as the House Committee on Science, Space, and Technology, the House Committee on Energy and Commerce, and the Senate Committee on Commerce, Science, and Transportation, would be the appropriate focal points. Ties with the budget committee and key appropriations committees are also very important. The congressional support agencies, OTA in particular, should also play a direct role by undertaking analyses, at the request of congressional committees, of the issues and advice that the Forum generates.

It would be highly desirable if, early in a new administration, the Assistant to the President for Science and Technology and the leadership of Congress or the chairmen of key committees requested that the Forum undertake its activities. Alternatively, Congress could request or "authorize" the Forum's activities through a concurrent resolution, a nonbinding indication of the opinion of Congress. In this way, the Forum would operate on a four-year cycle, with a continuation of activities being contingent on future requests or "authorizations" from the executive and legislative branches of government. Recognition of this kind would help assure the utility of the Forum's products.

We believe that initial funding for the Forum should be sought primarily, although not exclusively, from private foundations. Once the Forum process has proven itself, activities might be funded jointly by the federal government and private foundations.

ROLE OF CONGRESS

■ **Congress should devote more explicit attention to long-term S&T goals in its budget, authorization, appropriation, and oversight procedures.** Congressional support is key to the long-term productivity of science and technology. Budget, authorization, appropriation, and oversight procedures are complex and highly decentralized, and there are opportunities to improve the ways in which Congress addresses S&T issues. We have not, however, focused too closely on these opportunities. The Committee on Science, Technology, and Congress of the Carnegie Commission will address these issues in an upcoming report.[31]

We believe that one of the most effective ways for Congress to consider S&T issues in the longer term would be for the House Committee on Science, Space, and Technology, which has responsibility for cross-cutting science policy considerations, to hold a series of hearings, on an annual or biennial basis, on long-term goals for science and technology. The purpose of these hearings would be to step back from the budget process and consider science and technology from the long-term perspective. However, we also believe that each legislative committee in the House and Senate with jurisdiction over major segments of federal S&T activities should periodically, perhaps biennially, devote formal attention to questions of long-term S&T goals in its area of responsibility.

Congressional committees could ask the appropriate federal agencies and a full spectrum of responsible nongovernmental interests, including the proposed National Forum on Science and Technology Goals, for their views on long-term S&T goals. They could also hold hearings, and issue reports embodying the committees' conclusions. Specifically, as the proposed Forum matures and gains public confidence, the committees with significant responsibility in S&T areas could serve as focal points for communication with the Forum in the legislative branch.

These committees, along with leadership of the Senate and the House of Representatives and supported analytically by OTA and the other support agencies, may wish to develop mechanisms to use the Forum's output throughout congressional S&T policymaking activities. This might include ensuring that long-term goals as articulated by the Forum and other groups are considered as the various congressional committees plan their hearings and legislative agendas, and ensuring that critical science and technology issues are taken into account when the leadership determines the legislative agenda for each session of Congress.

ROLE OF THE CONGRESSIONAL SUPPORT AGENCIES

▪ **In order to provide Congress with the information, analysis, and advice necessary to make policy decisions in this area, the Office of Technology Assessment and other congressional support agencies should evaluate national efforts to establish and achieve long-term science and technology goals in the context of societal goals.** The support agencies should work with congressional committees to consider what kinds of analyses of long-term S&T goals would help inform their legislative agendas. OTA, in particular, should apply its well-tested assessment process to the task of undertaking analyses, convening expert panels, and monitoring progress in the establishment and achievement of long-term S&T goals. The Congressional Budget Office (CBO), although it has limited responsibilities for S&T policy, has considerable expertise in economic analysis, which is an essential part of establishing and achieving long-term S&T goals. CBO should put its expertise to use in evaluating economic considerations with respect to long-range science and technology policy.[32]

More specifically, we believe that CBO and OTA should establish an ongoing coordinated activity designed to combine their strengths in analyzing economics and science and technology, respectively, in order to evaluate goals and budget priorities for science and technology. Furthermore, because we believe that interactive linkages are the key to solving complicated problems, we suggest that OTA, with the cooperation of the other congressional support agencies, assist congressional committees and the congressional leadership in reviewing and analyzing the products of the Forum.

ROLE OF OSTP AND OMB

■ **The Office of Science and Technology Policy and the Office of Management and Budget within the Executive Office of the President should actively contribute to the establishment of federal science and technology goals and should monitor the progress of departments and agencies in attaining these goals.** Establishing long-term goals and communicating them to the federal agencies is a process that must be conducted separately from the annual budget process. With a goal in mind, the agencies can create a budget that balances their vision of the future with the realities and constraints of the present.

OSTP and OMB should communicate long-term S&T goals to departments and agencies before the beginning of the budget cycle each year. In addition, both OSTP and OMB should work with these departments and agencies throughout their budget planning processes to assure that long-term S&T goals are considered and advanced in their internal policy-planning activities.

OSTP should also monitor the progress of federal programs in achieving long-term S&T goals and report its findings to the President and Congress. In particular, OSTP should function as one liaison point between the National Forum and the Executive Branch. With OSTP leadership, the Federal Coordinating Council on Science, Engineering, and Technology (FCCSET) should extend its promising efforts in shaping long-term S&T goals involving more than one federal agency. Furthermore, the President's Council of Advisors for Science and Technology (PCAST) should play a more extensive role in guiding the goal-setting process within the Executive Office.

Efforts to monitor the success of government programs can be greatly aided by the establishment of specific goals. Legislation is pending in Congress that would require federal departments and agencies to establish a "performance standards and goals plan" for major budget expenditure categories. A key element of these plans would be performance indicators that could be used to track progress in achieving goals.[33]

ROLE OF THE FEDERAL DEPARTMENTS AND AGENCIES

■ **Federal departments and agencies should enhance their policymaking efforts, integrating considerations of long-term science and technology goals into annual budgeting and planning efforts.** Federal agencies should enhance their strategic planning capabilities and develop explicit long-term S&T goals in the context of broader national goals established by Congress and the President. In order to do this, open communication and cooperation among the senior R&D administrators of departments and agencies should be encouraged. These individuals should meet periodically to discuss longer-term objectives and ways in which their work might contribute to or compete with broader goals and stated policies. Furthermore, federal agencies should be required to present publicly each year an analysis of how their planned activities relate to their long-range S&T programs. Resources to support the achievement of these goals should be incorporated into annual budget plans.

In addition, we recommend that federal agencies support extramural policy studies that can aid in developing and evaluating long-term S&T goals. The National Science Foundation (NSF) should develop and monitor indicators of the health and productivity of the science and technology enterprise and its contributions to societal goals. NSF should expand its competitive grants program in science and technology policymaking and work to involve scientists and engineers in the S&T goal-setting process. NSF, in conjunction with OSTP and other federal agencies, should establish continuing programs to develop the information base necessary to monitor progress in achieving long-term S&T goals. Furthermore, the National Science Board should assume greater responsibility for devising approaches to long-term goal-setting with respect to the S&T base. We note that the National Science Board has the authority to establish special commissions and committees to focus on specific policy questions.[34] The Board could periodically convene such panels to examine, for example, the long-term directions of certain scientific disciplines.

5

GOAL-SETTING, S&T, AND SOCIETY: A LOOK AT THE FUTURE

At the beginning of this report we said that America faces a choice between business-as-usual in science and technology policy and a new approach that would place more emphasis on long-term S&T goals and on clarifying the linkages between the S&T enterprise and societal goals. We believe that this choice is especially critical because of the historic opportunities our nation has been presented with, both by the end of the Cold War and by the dramatic developments in U.S. technology that could, if properly managed, revolutionize so many aspects of our society.

MAKING BETTER CHOICES

We believe that implementation of our recommendations will help America make better choices and move toward a new age of vitality and leadership in the world community. We are well aware that even if these recommendations are adopted, success will not come easily. The United States faces a host of pressing issues tied to science and technology. Some relate to our domestic economic performance and to international competitiveness: How can the nation modernize its industrial infrastructure? Can and should we maintain the strong position we hold in certain key high-technology industries and also reclaim a strong position in others? Some issues have come to the fore because of the end of the Cold War: How can funds for defense R&D be shifted to civilian R&D? Can some of the weapons-related R&D activities of the Department of Energy's national laboratories be shifted to support other priorities, such as environmental technology development?

Still other pressing issues, which have received less public attention, concern the S&T base: How can we improve math and science instruction in our schools? Are we producing the right mix of scientists and engineers? How can we replace aging research facilities?

Other issues have been developing slowly but are becoming more urgent: balancing environmental concerns with the search for cheaper energy, controlling the costs of high-technology medicine, dealing with global climate change, confronting the telecommunications revolution. Too often in the past the goal-setting process seemed to stop once a goal had been agreed upon. The result has been that competing short-term political and economic interests have sidetracked or distorted agreed-upon objectives. Effective goal-setting requires that policymakers continue to work to achieve and maintain support for a goal over time, monitoring developments to ensure that progress continues toward the goal.

PERSISTENT CHALLENGES

While the recommendations made here should help the United States seize a historic opportunity and deal with pressing issues, they will not solve all of our science and technology policymaking problems. In particular, we see three areas that will present persistent challenges.

Competition for Federal Funds

The first challenge grows out of the continuing competition for federal funds for S&T. Because of this competition, we can expect that scientists within specific disciplines will contend with each other for resources and that they will appeal to long-range societal needs to win greater funding. Consider biology, for example. Supporters of the human genome project believe that sequencing the human genome will serve key societal goals related to quality of life, health, human development, and knowledge. In particular, they feel that the sequence would create a complete library of information that biologists could search as they strive to understand human gene expression; and the sequenced genome would enable researchers to understand the mechanisms underlying genetic diseases, eventually allowing the development of therapies to treat them. Other biologists appeal to similar societal goals, but argue that sequencing the human genome would take resources from other research activities. Some argue that human health and well-being would be better served by devoting more resources to understanding fundamental developmental biological processes, or to cataloguing biodiversity, or to more research on epidemic diseases, especially AIDS or cancer. This kind of debate is sure to recur elsewhere.

There will be similar conflicts between the sciences, with each side appealing to a societal goal, often the same goal, in an effort to secure scarce resources. For example, recapturing America's economic leadership is a goal most Americans would agree is especially important. Biologists have argued that biotechnology is one key to restoring American competitiveness. It is clearly a growing field and one in which the United States is a leader. Physicists and electrical engineers, on the other hand, argue that the United States should not overlook superconductivity, another highly promising area. Unless government and industry devote resources to developing this field, it is argued, we may lose out once again to foreign competitors. Clearly, different scientific disciplines may have equally valid claims on a particular societal goal, while having to compete for limited resources.

Choosing between Goals

The second area where problems are sure to persist involves choosing between goals. While this is outside the scope of this report, it is clear that in order to achieve long-term S&T goals the public and their elected representatives will have to decide which societal goals are most important. Sometimes science and technology policy can help society only if the public is willing to make a tough choice, supporting one goal over another. Some political observers have argued that Americans have in recent years become unwilling to make these kinds of choices. They trace the deadlock over the federal budget, for example, to the public's desire to have lower taxes *and* larger entitlement programs. An unwillingness to choose between societal goals will clearly make it difficult to choose between long-range S&T goals that are linked to societal aspirations.

Public Enthusiasms

The third area of continuing problems is the sudden swing in public enthusiasm for specific goals. For example, the oil shortages of the 1970s placed energy efficiency and alternative fuels high on the list of societal goals. Resources flowed into solar power, oil shale, geothermal energy, and other alternative energy sources. But public concern declined rapidly during the 1980s, and resources for alternative fuels began to shrink. Sudden swings of enthusiasm and commitment make it difficult for S&T to support national objectives effectively.

A SHARED BURDEN

All major institutions in the science and technology communities share the burden of ensuring long-term progress in their fields, and they should work together to achieve broad societal objectives. As Albert Einstein said, "the concern for man and his destiny must always be the chief interest of all technical effort: Never forget it among your diagrams and equations."[35] In our report, we have sought to highlight the importance of linking the "diagrams and equations" developed by scientists and engineers more closely with the aspirations of the public for health, prosperity, and security in an effort to help our nation enable its own future.

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MEMBERS OF THE TASK FORCE ON ESTABLISHING AND ACHIEVING LONG-TERM S&T GOALS

H. Guyford Stever (Chairman), a member of the Carnegie Commission on Science, Technology, and Government, was Director of the National Science Foundation from 1972 to 1976; during this time he also served as Science Advisor to Presidents Nixon and Ford. He was Director of the White House Office of Science and Technology Policy from 1976 to 1977. Before joining NSF, he was a professor at MIT from 1945 to 1965 and President of Carnegie Mellon University from 1965 to 1972.

Harvey Brooks served as dean of engineering and applied physics at Harvard University from 1957 to 1975. A solid state physicist, he worked in atomic power for the General Electric Company before joining Harvard. After his tenure as dean, Dr. Brooks became Peirce Professor of Technology and Public Policy and was one of the founders of the program in science, technology, and public policy at the Kennedy School of Government.

William D. Carey was CEO of the American Association for the Advancement of Science from 1975 to 1987. He is currently a consultant to Carnegie Corporation of New York. Before joining Carnegie, he served as vice president of Arthur D. Little, Inc., following a long career as Assistant Director in the Bureau of the Budget, Executive Office of the President.

John H. Gibbons has served as the director of the congressional Office of Technology Assessment since 1979. Before his appointment, he directed the Energy, Environment, and Resources Center at the University of Tennessee. Beginning in 1954, he spent 19 years with the Oak Ridge National Laboratory in various research and management positions.

Rodney W. Nichols is CEO of the New York Academy of Sciences. He was Executive Vice President of Rockefeller University from 1970 until 1990, having served as special assistant for research and technology in the office of the Secretary of Defense from 1966 to 1970. He is a member of the Carnegie Commission's Executive Committee and was Scholar-in-Residence at Carnegie Corporation from 1990 until 1992.

James B. Wyngaarden is Foreign Secretary of both the National Academy of Sciences and the Institute of Medicine. In addition, he is Associate Vice Chancellor for Health Affairs at Duke University. He was Director of the National Institutes of Health from 1982 to 1989, and he recently served as Associate Director for Life Sciences in the White House Office of Science and Technology Policy.

Charles A. Zraket is a Scholar-in-Residence at Harvard University's Kennedy School of Government. He joined the Mitre Corporation in 1958 and held numerous positions there, serving as president and CEO from 1986 to 1990; he is currently a member of the Board of Trustees. Before his career at Mitre, he conducted research at the Massachusetts Institute of Technology for seven years. He is a member of the Carnegie Commission's Advisory Council.

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Mr. BOUCHER. Thank you very much, Dr. Stever.

Dr. Wiley?

Dr. WILEY. Mr. Chairman, I am John Wiley, dean of the Graduate School at the University of Wisconsin in Madison. From about 1990 through 1992, I served on the Government-University- Industry Research Roundtable's Working Group on the Future of the Academic Research Enterprise—a big mouthful there. This is the group that prepared the report entitled, "Fateful Choices: the Future of the U.S. Academic Research Enterprise."

In my oral testimony I'll follow the lead of earlier witnesses and assume that you have access to our report already, defer any summary of that report to any questions you may have later on, and move directly to the NSB Commission report, with one small exception. I'd like to point out I did include with my testimony one of the principal outcomes of our working group, the scenario diagram for the future of the enterprise. I'd like to point out that no one area of that future scenarios diagram is inherently better than where we are on it today. Where we go in the future will depend on our own judgments as to the science and engineering capacity needed by the Nation and the degree of technological risk we're willing to assume. How well we function when we get there will depend on knowing where we are and providing the funding and infrastructure needed for that particular configuration.

Turning now to the report of the Commission, I believe that the Commission's recommendations are fully consistent with everything we learned and concluded during two years in which the working group received testimony and prepared "The Fateful Choices" report. I'd particularly like to call your attention to what I consider to be the most important language outside of the recommendations themselves in that report. It occurs on page 3, and Bill Danforth already entered it into the testimony here today by quoting it verbatim. So I won't repeat that. This is the language having to do with failures in the marketplace not being due to slow technology transfer from academic research.

Instead, I'd like to restate the essential message in different language. The most important thing universities do to transfer technology to the private sector is to assure that each new generation of science and engineering graduates takes into the private sector the basic skills and the scientific and technological expertise required to face today's challenges and to adapt to the challenges of tomorrow.

The Working Group on the Future of the Academic Research Enterprise, like the Commission on the Future of the NSF, heard this message repeatedly and emphatically from industrial scientists, engineers, and managers. And I believe you've heard it again this morning from Dr. Rushton.

Concerning the numbered recommendations, I believe the Commission's report is an excellent one, and I urge you to give all of their recommendations your most serious consideration. In my written testimony I've commented on several of the specific recommendations. Today I'll mention only one.

Concerning general recommendation No. 5, increased private sector involvement in the NSF decisionmaking process, I'd like to add a note of caution with my overall support for this recommendation.

The challenge of making wise decisions concerning resource allocations in science and technology is so great that it cannot afford to ignore any important inputs. We should not be misled into believing, however, that scientists, engineers, and managers in the private sector have anything more than one more valuable perspective to add. In particular, they do not have any special insights that would make them better able to predict the course of scientific discovery or to do accurate technology forecasting.

I can cite numerous examples, including examples from my own personal experience in industry, of technologies into which entire industries have poured hundreds of millions of dollars, billions of dollars in some cases, in the mistaken belief that they were advancing commercially viable products and processes. At the same time, I can cite examples of small, apparently useless or curiosity-driven projects in those same companies that ultimately did lead to major economic payoffs.

While it is not wise to attempt to make policy from isolated examples and anecdotes, the underlying truth here is that research leading to scientific technological advances is, by its very nature, always difficult to predict and impossible to predict accurately.

This brings me to my final point. In my testimony I have followed the widespread practice of referring to basic research and applied research. As you, Mr. Chairman, said earlier, these are easy words to say and difficult to apply. The search for a meaningful distinction between basic and applied research is something I've grappled with, as most of my colleagues have, throughout my entire career, first in industry and now in academia. I have concluded that there is no qualitative difference that stands up to objective analysis or that provides any generally useful guidance in judging the worthiness or economic value of research projects in a given area.

It seems to me that the entire debate would benefit from dropping this terminology in favor of focusing on the expected time scale for economic payback. What many now call applied research would be relabeled "near-term research," and what is now sometimes dismissively referred to as "basic or curiosity-driven research" would be acknowledged as long-term research.

All parties, particularly the researchers themselves, recognize that the support of a large academic research enterprise requires a large and healthy economy. It has always been the case that the level of support for even the most basic and long-term scientific and engineering research depends on the expected eventual payoff in terms of solving important social and economic problems.

The NSF maintains a portfolio of programs and projects that is balanced over both research areas and research time scales. That balance is a remarkably dynamic one that is very responsive to national needs. I really do not believe that any major shifts or corrections are warranted. In particular, it calls for the NSF to support more applied research or asking the Foundation to pull in its time horizon and tilt its research portfolio much more toward projects that have easily predicted, near-term payoffs. Then I submit that the Foundation is being advised to make the same mistakes that have caused many of our industries to lose their competitive edge. That would be a tragic mistake for the country, and I believe that in this judgment I'm once again agreeing with the NSB Commission's report.

Thank you, Mr. Chairman.

[The prepared statement of Dr. Wiley follows:]

JOHN D. WILEY

DEAN, THE GRADUATE SCHOOL
UNIVERSITY OF WISCONSIN-MADISON

TESTIMONY

U. S. HOUSE OF REPRESENTATIVES
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

MARCH 3, 1993

Mr. Chairman, members of the Committee, I am John Wiley, Dean of the Graduate School at the University of Wisconsin in Madison, Wisconsin. I am a physisist by training, and am a tenured member of our department of Electrical and Computer Engineering. Prior to joining the faculty, I spend about seven years as a staff scientist at Bell Telephone Laboratories, where I worked on optoelectronic devices, microwave transistors, and magnetic bubble memory device materials. During 1991 and 1992, I served as a member of the Government-University-Industry Research Roundtable's (GUIRR) Working Group on the Future of the Academic Research Enterprise - the group that released, almost exactly one year ago today, a report entitled *Fateful Choices: The future of the U. S. Academic Research Enterprise* [1]. It is because of my participation in the preparation of that report that I have been asked to testify here today, and to comment on any implications our report may have concerning the future mission of the National Science Foundation.

In my testimony, I will first attempt to summarize the *Fateful Choices* report, emphasizing the critical roles the Working Group envisions for the academic research enterprise, and the scenarios we developed as a framework for thinking about the funding, human resource, infrastructure, and other requirements and implications implicit in any conceivable national and institutional plans. I will then try to relate our report to the recent report of the National Science Board's Commission on the Future of the National Science Foundation. Finally, I will conclude with a few observations from the perspective of a single university research administrator.

Fateful Choices

The first sentence of *Fateful Choices* sets a promising tone that could hardly fail to draw researchers eagerly into the text: "The academic research community in the United States is headed toward an era of unparalleled discovery, productivity, and excitement." Readers will quickly find, though, that this apparently optimistic vision may or may not be realized. Hence, the overall theme - "Fateful Choices." One of the principal conclusions that I believe essentially all members of the Working Group reached, after two years of deliberations, and volumes of testimony from all interested sectors, is that the future health of the academic research enterprise depends at least as much on how it is organized, and on the quality of national and institutional planning and coordination, as it does on the absolute levels of research funding. To a Congress faced with staggering budgetary problems and no shortage of worthy investments to consider, this may seem like very good news, indeed. I must tell you, though, that every future scenario carries with it its own set of costs, tradeoffs, and risks, not all of which can be reliably assessed in advance.

The Environment

Turning to the *Fateful Choices* report, itself, I would like to begin by restating the four factors identified by the Working Group as setting the environmental context within which the academic research enterprise will have to evolve and adapt in the coming years. They are, without elaboration here:

1. a global research system;
2. a diverse research workforce;
3. new communications technologies; and
4. an expanded role for academic research.

Leaving aside #4 for now, these environmental factors will unquestionably have a profound effect on the conduct of academic research and graduate education regardless of the future paths along which we evolve. All of the present research universities and all universities that aspire to join that group will need to address these factors strategically if they expect to be significant participants in the future. Factors 1-3 are so broad, however, that they leave a great deal of latitude for institutions to devise successful strategies that take advantage of their particular strengths and circumstances.

Regarding #4, an expanded role for academic research, what is described in the report is an increasing importance of the present role (conducting a major fraction of the nation's basic research, while using that research as a vehicle for training the next generations of scientists and engineers), and an increasing involvement in the processes of transferring research results directly into practical and commercial applications.

There can be little doubt that universities conduct a major (and increasing) fraction of all basic research in the U.S. Indeed, an earlier Roundtable report [2] estimates that the fraction of U.S. basic research carried out by universities increased from about 25% in the early 1950s to more than 50% in 1970, and that the percentage has remained at approximately 50% to the present. These are very likely underestimates, as private-sector research organizations label as "basic" many activities that university researchers would consider strongly applied research, if not early development. It is interesting that, of the 250 Nobel Prizes that have been awarded in medicine, chemistry, and physics since 1901, fully one third (84) have been for work done at U.S. universities. Only 13 went to U.S. research groups at organizations other than universities, and three of these involved collaborations with universities. If anyone is inclined to dismiss this statistic as some form of "proof" that academic research is too "basic" to be of practical value, I hasten to point out that included among these awards for basic research done at universities are many for work that has subsequently led to commercially important products or, indeed, to entire industries. (e.g.: streptomycin, CAT scanners, NMR, MASERS and LASERS, the entire underpinnings of modern biotechnology, and scientific contributions crucial to the application of several classes of chemicals and engineering materials.) That the researchers, who carried out this work with graduate and post-doctoral students, were simultaneously training the next generations of scientists and engineers makes the work more than doubly important to the nation.

University dominance of the U.S. basic research effort is likely to increase as the list of once-eminent industrial research laboratories that have been closed or converted to short-term R&D continues to lengthen. At the same time, however, the report labels as an "urgent challenge for the future" the need to "transfer the knowledge gained from basic research more rapidly to the nation's commercial sector." This "urgent challenge," depending upon exactly how it is interpreted and met, could well carry more profound implications for graduate education than any other aspect of the report. In the spirit of the Working Group's practice of crystallizing issues for debate rather than entering the debate directly, I will simply point out that this issue is one that deserves the most serious reflection and discussion by all interested parties. Is there an appropriate balance (in universities) between basic

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and applied research? Are there types of applied research that are simply inappropriate as vehicles for graduate education? Do we have adequate guidelines for the appropriate division of faculty time among teaching, research, and direct involvement in technology transfer or related commercial activities? Do we have adequate guidelines for all parties to follow in avoiding conflicts of interest? Should we be devising more flexible PhD programs that allow students to move more easily between periods of university work and commercial employment (transferring technology as it is being developed)? These and many other issues are already being faced at our universities. But if, as the report suggests, the entire academic research enterprise is being moved inevitably into closer working relationships with the commercial sector (and, very likely, more research that would once have been called applied), it is unlikely that many of our current guidelines and practices will suffice.

The Size and Configuration of the Academic Research Enterprise

The bulk of the *Fateful Choices* report is devoted to discussing nine possible scenarios that result from changing (or not) the overall size of the academic research enterprise and/or the configuration of academic research institutions. By "size," the Working Group meant some vague measure of the total number of researchers and research institutions, as well as the total level of research funding. By "configuration," they sought to define a scale along which the degree of specialization of the research institutions changed. At one extreme (which is referred to as the "diversified" end of the scale), most research universities would have chosen to focus on a (relatively) small number of research areas in which they seek to excel. At the other extreme, most research universities would be comprehensive, attempting to sustain excellence "across the board."

Included with this testimony are two pages of diagrams illustrating the scenarios and their consequences. The first page, entitled "The Nine GUIRR Scenarios," shows our present size and configuration in the center, with eight possible future scenarios surrounding it. The second page of diagrams shows a few of the major trends and implications associated with moving the research enterprise on the scenario diagram.

Three of the nine scenarios involve an increase, a decrease, or no change in the overall size of the enterprise within the present distribution of institutional scopes and missions. These three scenarios all (even the status quo) have significant implications for the nation in terms of the quantity of research accomplished and the supply of scientists and engineers. They would not appear to have a major impact on graduate education *per se*, however.

Changing to a configuration in which we have either many more "comprehensive" universities or many more "specialized" universities, on the other hand, could have major cost, human resource, infrastructure, and policy implications, not to mention major implications for graduate education. To put this in perspective, it is worthwhile to survey the present configuration of academic research institutions in the U.S.

Although we have more than 2,100 four-year colleges and universities in the U.S., only about 70 of them (3.3%) are classified as "Research I Universities." These research universities, which are distributed among 32 of the 50 states, conduct more than 80% of all the funded academic research, and produce more than 70% of all the PhDs. Thus, the "academic research enterprise" actually involves a relatively small number fraction of our total higher education system.

Interestingly, in 1906, there were only about 15 "major research universities" in the U.S. Today, all but four of those institutions are still among the top 20, and nine of the 15 are still among the top 15 in total research volume and the production of PhDs. The new entries are all large public universities that have displaced relatively smaller private universities. Thus, there has been a significant "payoff" for early investment, and a high cost (affordable only by states willing to invest heavily in rapid expansion) associated with entering the uppermost ranks on a timescale of a few decades. Few industries have seen such a small turnover among the ranks of their largest companies. In view of this small turnover at the highest ranks, and the present existence of some 70 Research I universities located in every region and every populous state in the country, it is likely that any reconfiguring of the academic research enterprise will be overwhelmingly confined to that group. (i.e., It seems unlikely that even under significant growth scenarios there will be very many additions to or deletions from the present list of research universities.)

If this assumption is correct, what are the extremes of possible reconfigurations among the roughly 70 institutions? If all 70 institutions grew to sizes that equaled the average of the top 20 institutions (and if the latter institutions remained at about their present sizes), the academic research enterprise would be capable of producing about 50,000 PhDs/year at a cost of about $7B/year above current academic research expenditures (a total annual cost of about $22B compared to current annual research expenditures of about $15B). This represents a roughly 50% real increase in the enterprise, exclusive of the costs associated with ramping up the research infrastructures of the 50 or so smaller institutions.

In the past, increases of a similar magnitude have occurred in times as short as six years during periods of rapidly increasing demand for PhD scientists and engineers. Given that our PhD production has been nearly static for more than ten years, we are unlikely to see a rapid rise in demand in any near-term six-year period. It is also not clear that the nation needs, or can sustain, such a large number of large comprehensive universities. It would imply a great (possibly excessive) increase in the duplication of the most specialized departments and facilities, for example. Nevertheless, the size and cost estimates provide useful benchmarks for a scenario in which the nation moves toward the development of a larger number of similar-sized comprehensive research universities. This is likely the most expensive of the nine scenarios presented in the report.

It is also the "safest," however, in the sense that, with redundancy comes robustness. This is the fundamental principle upon which all "fault-tolerant" systems are built. Research, by definition, attempts to answer questions for which we have no present answers. Research is inherently an uncertain undertaking, with no guarantee of success for a given approach. To the extent that we permit and support larger numbers of competing centers of excellence in a given critical technology area, larger numbers of them can make what will later be judged to have been serious mistakes in research directions without damaging our national position in that area.

The other major set of scenarios, in which schools become individually more specialized, emphasizing a greater degree of complementarity and cooperation at reduced levels of duplication and competition, has a great deal to recommend it, and is discussed extensively in the report. This is the direction in which the recent PCAST report suggests we should move as a nation. With adequate national planning, this option reduces duplication and competition-driven cost pressures, and provides more institutions with a claim to national prominence. It also carries significant national risks and vulnerabilities (which should be viewed as another form of "costs"), because it represents the opposite of the "safe," or highly redundant scenarios described earlier.

As the report notes, a smaller enterprise (but "at sustained funding no less than current levels") consisting of fewer comprehensive and more specialized institutions is likely the most inexpensive option in terms of infrastructure investments and annual operating costs. To benchmark this scenario with averaged numbers: If the present research expenditures were distributed more-or-less equally among the 70 Research I universities, each institution would have annual research expenditures of about $160M. Currently, about 25 institutions are at or above that level, and 45 are below. Initially, these funds would be enough to sustain approximately the current number of investigators and current graduation rates but, unless funding increases kept up with inflation, the overall enterprise would stabilize at a lower level (fewer investigators, fewer graduates). Theoretically, this scenario provides the lowest level of cost inflation by minimizing duplication, but the cost of maintaining current productivity levels will increase in any case.

As emphasized in the report, the "specialization" scenarios require by far the greatest degree of national planning and inter-institutional cooperation and communication. These scenarios would bring more multi-campus collaborations, more remote delivery of courses and seminars (made affordable through improved communications networks and teleconferencing facilities), and probably a much greater rate of student transfers among institutions. To the extent that the nation maintained fewer specialized research facilities, there might also be increased travel among institutions, although part of the logic of specialization is to concentrate specialists and their facilities at fewer places. Students who knew what they wanted would have fewer options to choose from, and faculty advisors would have to do more careful and thorough jobs in steering students to those options that are "right" for them, including urging students to transfer to another school if they have made the wrong initial choice. Funding agencies would need to resist the temptation to assist schools in launching new efforts that are not in their agreed "portfolio" of research areas. Finally, the intellectually "rich" environments of today's comprehensive universities would diminish, very likely to the great detriment of future (and currently unpredictable) interdisciplinary research areas. It is no accident that interdisciplinary research has flourished primarily at those institutions where the largest numbers of leading-edge researchers from many different research areas are in frequent and close contact in a variety of different settings.

Report of the NSB Commission on the Future of the NSF

Turning, now, to the report of the Commission on the Future of the NSF, I believe that the Commission's recommendations are fully consistent with everything we learned and concluded during the two years in which the GUIRR Working Group received testimony and prepared the *Fateful Choices* report. Before commenting on some of the Commission's specific recommendations, though, I would like to call to your attention what I consider to be the most important language in the report. It occurs on page three, and I will quote the relevant portions *verbatim*:

> "An important national priority is to improve the relative industrial strength of the United States. The National Science Foundation can make contributions to economic success, but developing a plan to do so must begin with an understanding of the system and of the reasons for failure of some industries in world markets.

> Failures in the market place have not been the result of slow transfer of academic science to industry. In fact, American firms have been the first to commercialize virtually all innovative products, but have lost market share to competitors with shorter product cycles, lower costs, and superior quality. All manner of other more prominent factors, including stewardship by American business, far outweigh whatever could be traced to the technology itself or the technologists."
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> and
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> "Redirecting NSF's activities from research and education would have little or no effect on the U.S. competitive position in the near term, but would severely restrict prospects for the long term. Research and education activities offer ample opportunity to increase the potential contribution of scientists and engineers to society."

The Working Group on the Future of the Academic Research Enterprise, like the Commission on the Future of the NSF, heard this message repeatedly and emphatically from industrial scientists, engineers, and managers. Restating the essential message in different language: **The most important thing universities do to transfer technology to the private sector is to assure that each new generation of science and engineering graduates takes into the private sector the basic skills, and the scientific and technological expertise, required to face today's challenges and to adapt to the challenges of tomorrow.** This is what industry really wants most from universities. Whatever may be our second most important mode of technology transfer is so much less important than producing high-quality graduates that it is "lost in the noise." In light of this fact, the NSF always has been, and I hope will remain, one of the major federal supporters of genuine, effective technology transfer.

In commenting on a few of the specific recommendations of the Commission on the future of the NSF, I must step back from my role as a spokesman for the GUIRR Working Group, and speak as an individual. This is because the Roundtable, as a matter of policy, does not make recommendations, nor offer specific advice. Rather, it brings all interested parties together to develop options and to provide a thoughtful context for planning and decision-making in its areas of interest. Thus, there are no recommendations in Fateful Choices that I might compare with those of the NSB Commission.

Speaking personally, then, I believe **the Commission's report is an excellent one, and I urge you to give all of the recommendations your most serious consideration.** In addition to the paragraphs I have already quoted, I would now like to highlight and comment on just a few of the specific recommendations:

General Recommendation #3 supports NSF's practice of encouraging investigator-initiated proposals and insisting upon peer review in the selection process. Continuation of these policies is vital. In some public discourse, the term "curiosity-driven research" has been used in a pejorative sense in the course of calling for more "strategic research." With only rare exceptions, this is a false issue. The funding agencies, including the NSF, already identify broad, strategic areas such as advanced materials, manufacturing sciences, and high-performance computing in which they invite proposals for possible funding. What they do not do (and should not do) is attempt to go further and define the specific research topics that will lead to the greatest advances or the largest payoffs. Those judgments are best left to the process in which thousands of our best scientists and engineers put forth their best ideas for competitive mutual evaluation. In our ferociously competitive funding environment (The NSF funds only about one third of the proposals it receives, and then only rarely at the levels requested.), there is ample incentive for researchers to propose projects that others will judge to be of the highest national significance, priority, and potential payoff.

The Commission's endorsement of the peer review process is a reaffirmation of the fact that no matter how critical or strategic a proposed research topic may sound, research that is poorly conceived and poorly executed serves no one's interests. In fact, poor-quality research in strategic areas may be doubly damaging if incomplete or misleading results are disseminated and relied upon while higher-quality work in that area goes unfunded. For any real or perceived flaws our peer review system may have, proposal review by acknowledged experts is by far the best way to assure the responsible stewardship of scarce resources and the protection of the integrity of our scientific and technological base.

Concerning General Recommendation #5 - increased private-sector involvement in the NSF decision-making processes, I would like to add a note of caution with my overall support. The challenge of making wise decisions concerning resource allocations for science and technology is so great that we cannot afford to ignore any important inputs. We should not be misled into believing, however, that scientists, engineers, and managers in the private sector have anything more than just one more valuable perspective to add. In particular, they do not have any special insights that make them better able to predict the course of scientific discovery or to do accurate technology forecasting. I could cite numerous examples (including examples from my personal experience in industry) of technologies into which entire industries poured hundreds of millions of dollars in the mistaken belief that they were advancing commercially viable products and processes. At the same time, I could cite examples of small, apparently "useless" or "curiosity-driven" projects in those same companies that ultimately did lead to major economic payoffs. While it is not a good idea to attempt to make policy from isolated examples and anecdotes, the underlying truth, here, is that research leading to scientific and technological advances is, by its very nature, always difficult to predict, and impossible to predict accurately.

The Commission's ten recommendations listed under "Research Recommendations" are all excellent. I would particularly call your attention to recommendations #4 and #10, both of which, I realize, imply the need for further increases in the NSF budget at a time when budget increases are most difficult. Speaking as a university administrator, now, I must tell you that, over the last ten years, the NSF has become increasingly insistent on "institutional cost-sharing." That is a concept that sounds appropriate on the surface, and is appropriate to some limited extent. I believe, however, we have now exceeded the limit. Universities are not profit-making entities. Our major sources of funds are student tuition, state support in the case of public institutions (primarily as a tuition subsidy for in-state students), and gifts from alumni who wish to support specific, targeted activities. Which of those sources should we tap for further increases in cost-sharing? The limited funds we have for cost-sharing on specific research projects have already been identified and counted. It is time for the NSF to return to its historic practice of providing something closer to full funding for those projects judged most worthy of support.

The final recommendation on which I will have a specific comment is Structural Recommendation #1. Here, the Commission encourages the National Science Board to devise additional metrics for evaluating the effectiveness of the research supported by the NSF. Although the private sector and the national laboratories have invested a great deal of time and money in largely unsatisfactory attempts to do this, it remains a worthy goal, and one that should be supported. I would urge, however, that the NSB take a relatively long view, attempting to evaluate the consequences of work initiated perhaps 10 or 15 years earlier (as opposed to doing annual evaluations of the economic impacts of currently-funded work, for example).

This brings me to my final point. Throughout my testimony, I have followed the widespread practice of referring to "basic research" and "applied research." The search for a meaningful distinction between basic and applied research is something I have grappled with throughout my entire career, first in industry, and now in academia. I have concluded that there is no qualitative difference that stands up to objective analysis or provides generally useful guidance in judging the worthiness and economic value of research projects in a given area. It seems to me that the entire debate would benefit from dropping this terminology in favor of focusing on the expected timescale for economic payback. What many now call "applied research" would be relabeled "near-term research," and what is now sometimes derisively referred to as "basic research" would be acknowledged as "long-term research."

All parties, including particularly the researchers themselves, recognize that the support of a large academic research enterprise requires a large and healthy economy. It has always been the case that the level of support for even the most basic (or "long-term") scientific and engineering research depends on the expected eventual payoff in terms of solving important social and economic problems. The NSF maintains a portfolio of research programs and projects that is balanced over both research areas and research time scales. The balance is a dynamic one that is remarkably responsive to national needs. I really do not believe that any major shifts or corrections are warranted. In particular, if calls for the NSF to support more applied research are asking the Foundation to pull in its time-horizon and tilt its research portfolio much more toward projects that have easily predicted near-term payoffs, then I submit that the Foundation is being advised to make the same mistakes that have caused many of our industries to lose their competitive edge. That would be a tragic mistake for the country, and I believe that, in this judgment, I am once again agreeing with the NSB Commission's report.

Conclusion

The Roundtable report "*Fateful Choices: The Future of the Academic Research Enterprise*" presents a valuable framework which can guide strategic thinking about how the U.S. can meet its scientific and engineering needs at a cost that is affordable and politically realistic. The report calls for extensive debate and for the development of new decision-making and priority-setting mechanisms. In this, it is fully consistent with the NSB Commission's report on the future of the NSF. In the coming debates, it will be most important to keep in mind, and to reaffirm, the DUAL importance of academic research and graduate education: The research itself is important, and its role as a vehicle for training the next generation of scientists and engineers is equally important. No matter how we organize, reorganize, and fund our academic research institutions, the nation has a great stake in our continued success in both areas.

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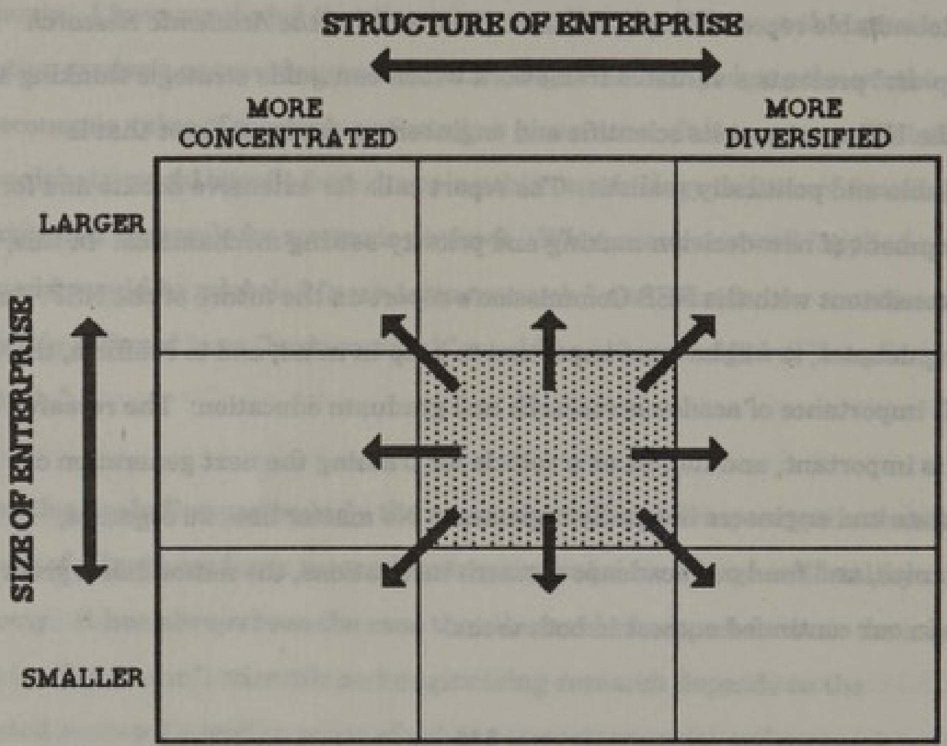
[1] Government-University-Industry Research Roundtable, *Fateful Choices: The Future of the Academic Research Enterprise,* National Academy Press, Washington, D.C., October 1989.

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

THE NINE GUIRR SCENARIOS

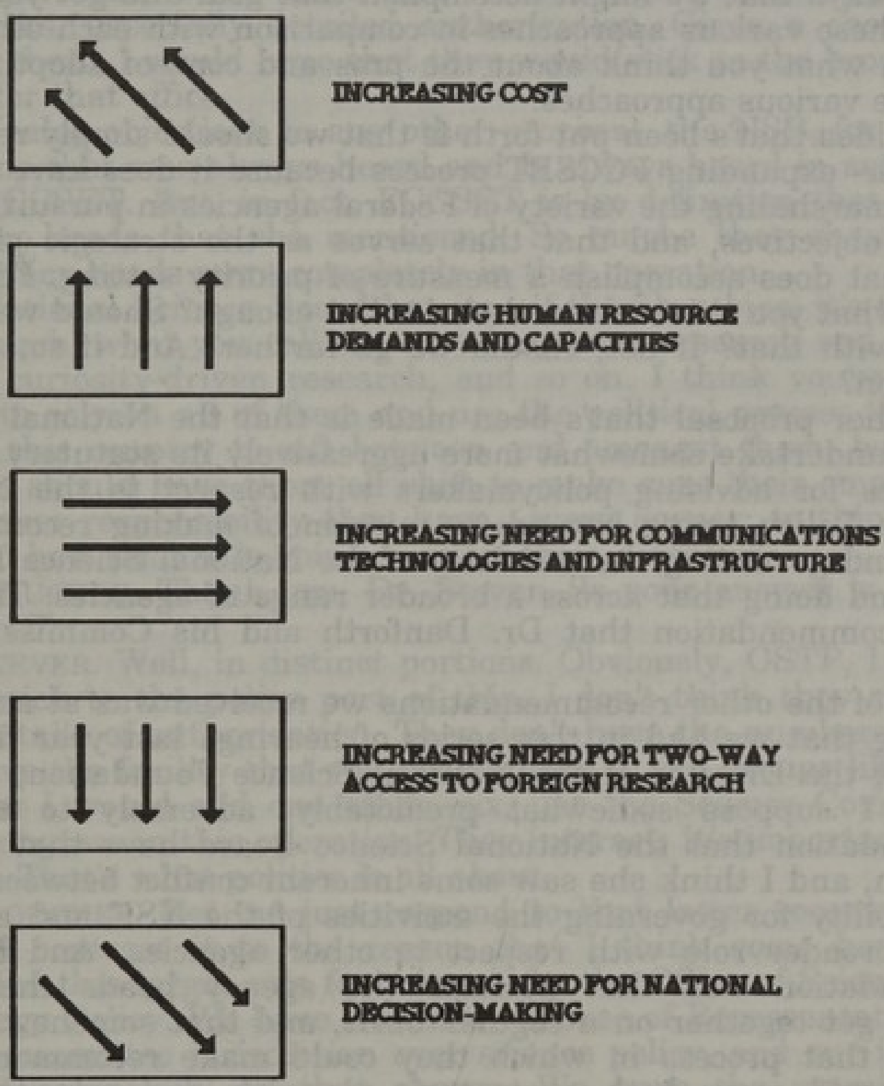
for the

FUTURE OF THE ACADEMIC RESEARCH ENTERPRISE



Adapted from *Fateful Choices: The Future of the Academic Research Enterprise*, (Government-University-Industry Research Roundtable, National Academy Press, Washington, March 1992).

TRENDS AND IMPLICATIONS
ASSOCIATED WITH THE
NINE GUIRR SCENARIOS



Mr. BOUCHER. Thank you, Dr. Wiley. And the subcommittee thanks each of the panel members for the time they've spent with us this morning and the thoughts that they have shared.

One thing that we are struggling with in the course of this inquiry is to try to determine how best to subpriorities, how best to structure a strategic plan for research, at a time when we have ever- increasing need for research funding and with limits being placed on the availability of dollars. And I'd like to just catalog for this panel some of the recommendations that have been made to us for ways that we might accomplish that goal and get you to critique these various approaches in comparison with each other, and tell me what you think about the pros and cons of adopting each of these various approaches.

One idea that's been put forth is that we should simply rely upon the ever- expanding FCCSET process because it does have the virtue of marshaling the variety of Federal agencies in pursuit of well-stated objectives, and that that serves as the strategic plan and that that does accomplish a measure of priority setting. I'd like to know what you think about that. Is that enough? Should we be satisfied with that? If not, should we go further? And if so, in what direction?

Another proposal that's been made is that the National Science Board undertake somewhat more aggressively its statutory responsibilities for advising policymakers with respect to the National Science Policy, going beyond its mission of making recommendations and governing the activities of the National Science Foundation, and doing that across a broader range of agencies. That was the recommendation that Dr. Danforth and his Commission had made.

One of the other recommendations we received was at an earlier hearing that we had in this series of hearings last year from Dr. Healey, the Director of the National Science Foundation, who reacted, I suppose somewhat predictably, adversely to the recommendation that the National Science Board have that broader mission, and I think she saw some inherent conflict between its responsibility for governing the activities of the NSF and applying some broader role with respect to other agencies. And her recommendation was that perhaps the agency heads themselves should get together on a regular basis, and that somehow we formalize that process in which they could make recommendations that would serve both a strategic planning and priority-setting function.

Another recommendation is that the Office of Science and Technology Policy be given the charge within the Executive Branch of essentially authorizing all research efforts and that no research effort could then be recommended to the Congress by the Office of Management and Budget until the Office of Science and Technology Policy had passed on that recommendation. In other words, formalize within OSTP the role of strategic planning and priority-setting.

And we've heard from this panel a recommendation that the National Academy of Sciences have a structure that would make periodic recommendations with regard to a strategic plan and priority-setting.

Given that range of recommendations to date, tell us what you think about the various ideas that have been put before us and assess those and critique them, if you would, and give us some guidance as to what direction we should embark in. Dr. Stever, I'd like to begin with you.

Dr. STEVER. Thank you very much. Mr. Chairman, thank you very much. I'm not sure I'd like to start it, but my comment is that you'd better use them all, at least a good grouping of them.

OSTP, especially with the down- structured size in the White House operation, OSTP itself will have difficulty handling all of these tasks, especially detailed authorization. Given a choice for roles for them, I would hope that they would stick to the broad policy role for that office.

The Healey objections to any other proposal, the NSB, for example, is one that was always heard and is always heard in activities of the FCCSET. But, in fact, FCCSET is by definition that group of agency heads that she mentioned. So maybe they should use those agency heads more completely in that operation.

The National Science Board has its—if there's a bias, it's toward the research, what you call the very long-term research and others call the curiosity-driven research, and so on. I think you're going to have to rely on all of them and use the political process that we have in this country to sift between and amongst them, but I do think we should have them all shift to make sure their emphasize in whatever responsibility they have—every agency, to think long term and how science is going to affect their activities.

Mr. BOUCHER. Thank you, Dr. Stever. So your answer is "all of the above?"

Dr. STEVER. Well, in distinct portions. Obviously, OSTP, I think, should stick to the policy part of this. I don't think they can get in the details of authorization. They don't have the numbers. They don't have the facility that you people have to call groups like this.

I guess I would add one other, six, use the Science Committee of the Congress in this operation. They interact. It's important they interact. That's what politics is all about.

Mr. BOUCHER. Let me just respond to that latter recommendation and contrast it to the reason that I think some have recommended this larger role for science, for the Office of Science and Technology Policy. We have within the House of Representatives in this subcommittee jurisdiction over science policy, and our inquiry is based essentially on that charge. We have the oversight of science policy.

But when you look at our legislative jurisdiction beside that general charge, it's really fairly small. This subcommittee has jurisdiction over the National Science Foundation and we authorize its programs. We have jurisdiction over the earthquake and fire programs, but even within the Science and Technology Committee we have to go to other subcommittees in order to talk about NASA programs and other kinds of research.

Then to look at research programs for the National Institutes of Health, we have to enlist the Energy and Commerce Committee. Agricultural Research is under the jurisdiction of the Agriculture Committee. Defense research is under the Armed Services Committee, and I could go on with additional examples.

To get an umbrella over the entire research establishment within just the House of Representatives, we would have to enlist about six standing committees within the House. It makes it a very cumbersome process and one that's very difficult to achieve.

Now the virtue of having the Office of Science and Technology Policy charged with a greater mission in this respect is that it does have a large umbrella, and the entire research establishment of the Federal Government could be directed to some extent if that office exercised a greater function in that regard. It's got the strategic location within the Federal Government to carry that out. Now I grant you it doesn't have the resources to do it, but let's suppose that we gave it the resources necessary to accomplish that task. Would we be on the right track, in your opinion?

Dr. STEVER. Yes.

Mr. BOUCHER. Thank you. That's a good, concise answer. I don't get those very often.

[Laughter.]

Dr. Nathans, would you like to contribute to this discussion?

Dr. NATHANS. Yes, thank you. I think that the President's Science Advisor, the head of OSTP, is the right place for the central role, for some of the reasons that you already mentioned. However, I think, with the exception of the National Science Board, all the groups you listed are all—and the National Academy of Sciences—within the Government. I'm concerned that there be adequate input from people outside the Government, such as the President's Council of Advisors on Science and Technology, which I think played that role; people from industry, from the academic sector. But I think some part of Government has to be the focus, and I think the President's Advisor's Office, OSTP, is the right focus for that. I think Allen Bromley has shown that you can actually get some results by organizing a group like FCCSET, and I think we ought to continue and exploit that.

I think the National Science Board certainly has a role to play. It doesn't seem to me, because of the overlap with its other functions, that it's the right place for the central role. I think one needs a very broad look at all the areas of scientific input from Government agencies to try to do something where there is overlap.

I think, incidentally, it might be an improvement to have the President's Science Advisor have some more input in regard to budgetary decisions on research rather than leaving it to the Director of OMB.

Mr. BOUCHER. Thank you very much.

Dr. Rushton, would you care to comment?

Dr. RUSHTON. Yes, Mr. Chairman. You'll have to forgive me if I give you a very simple-minded answer to a very complex issue, but I can only go on my instincts and the experience I've had over the last 30 years in industry on this particular matter. And in that 30 years, I have never found R&D or science as a whole to be particularly fruitful in industry unless it's actually coupled up with a strong strategy that supports and guides it.

I, therefore, feel, applying that common sense to this particular situation, it seems to me the natural place for such a development of strategy or development of technology policy is in the Office of the OSTP, in the Science Advisor. However, I'm also very, very familiar in industry that if you're not careful you get out of balance between the long- and the short-term issues that are involved here. And, therefore, I say I tend to favor possibly the mechanism that Dr. Stever recommended, that we get other agencies and others involved in this situation. And certainly in terms of the balance between the short- and the long-term, I think the National Science Board and the agencies themselves are best suited to balance out that long- and short-term issue under the guidance of the overall policy.

However, again, I feel that they, themselves, have to be open to inputs. Perhaps that's where organizations like the National Academy of Science come in, and I have to admit to a little ignorance on the overall missions of FCCSET. So I won't comment on that particular issue.

But that's my simple-minded answer to your question.

Mr. BOUCHER. Well, it's anything but simple- minded. It's a very thoughtful answer.

Let me ask you to comment, if you would, upon the quality of industrial input into the decisions that are made at the Federal level with regard to funding research. How adequate are our structures for soliciting that input? To what extent do you think the recommendations of the private sector are heeded and reflected in the decisions that are made?

Dr. RUSHTON. It's my personal opinion that there is a dearth of input from people in industrial research into the process. That doesn't mean to say there is none. There is some, I know that.

But it gets down, I think, to the two issues: first of all, the invitations to participate are not exactly—don't proliferate. And, secondly, if they did, all of us in industry, of course, are paid to do a job or work for our own industries, and that's where our main focus has to be. So we also have to balance our time commitments, but I do believe if the invitations were more forthcoming, then you'd probably get a lot of us stepping forward to help in this issue, which we think is of tremendous national importance at this moment in time.

Mr. BOUCHER. So what you're recommending is something like an affirmative action program on the part of Federal research agencies and policymakers to reach out to industry and solicit their advice on a somewhat more regular basis?

Dr. RUSHTON. I think so, yes.

Mr. BOUCHER. Okay. Dr. Wiley?

Dr. WILEY. I tend to agree with the answers that you've heard from my colleagues here, that a plurality of methods are needed. The one point that I'd like to make about the situation we have then on those that have been suggested is this: whatever we do to set up a system for planning national science and technology policy needs to be designed to avoid catastrophes that would result from making seriously flawed strategic decisions.

The natural tendency is to try to eliminate duplication wherever it exists in the name of efficiency and economy, and to eliminate confusion wherever it exists in the name of tidiness. But I would point out that every fault tolerance system that engineers design is designed intentionally to be redundant, so that if one part fails, another one can pick up the load. And that's a very important principle to keep in mind as we design systems for deciding national science and technology policy. Redundancy is the same as safety.

Mr. BOUCHER. Get a lot of advice, in other words. Good.

One of the questions that I think is worth exploring this morning is the recommendation that has been made by the PCAST study, in particular, about grant size. The average grant size at the National Science Foundation is about $50,000, and the PCAST study suggests that that ought to be larger. Actually, I guess it was the National Science Board Commission's recommendation that suggested that that perhaps should be larger. And the PCAST group in turn recommended that we should be looking toward greater specialization at research universities and that perhaps the duplications that exist at universities across the country today should be avoided in the effort to have greater specialization and perhaps a more efficient use, for that reason, of research dollars.

What happens if we adopt both of those recommendations? We would have larger grants awarded, presumably to fewer researchers, assuming constant dollars, and we would have perhaps fewer universities. At least, we would have more specialization among them. If both of those recommendations were adopted, do you think that the result might be a shrinkage in the size of the research force? And if so, is that in the national interest? Dr. Nathans, would you care to comment?

Dr. NATHANS. Well, given your premise that there wouldn't be an increase in overall funds, certainly what you suggest would follow. I don't think that is in the national interest. Now I don't think that asking universities not to try to do everything, if they can't do them all well, is—quite carries it to a point where they're highly specialized, but certainly it does mean concentrating their efforts. That doesn't necessarily mean downsizing. I think that's going to depend on the opportunities in particular fields.

Now, of course, the Commission report recommended increasing the budget to NSF along with increasing individual grant awards, and I think that the reasoning there is, in regard to increasing grant awards, is quite sound. I mean, you can't expect people to carry out the research that they intend to do if they don't have adequate funds. In other words, you can't just continuously dilute the individual awards, as is often done, and expect that you're going to get the same fruits from that research. And so I think you have to face up to that.

Now I think it's a strong argument that if we are to continue the productivity at increasing cost, which is the actual situation, it takes more funds.

Mr. BOUCHER. Okay. Any other comments on that particular question? Dr. Rushton?

Dr. RUSHTON. Yes, I have a comment. I always like to try to get the cake and eat it, so to speak, on these things. And I would ask the question here, and I don't know the answer, but I would ask the question, if $50,000 isn't enough, then how much is enough? Maybe it's $75,000; maybe it's $100,000. But, on the other hand, there is a limited amount of money, although it should be more, I concede. But perhaps the NSF should think more strongly about offering block grants along the same line for the same kinds of research to several universities. So instead of offering $50,000 to do a little on this and $50,000 to do a little on that, maybe they have to prioritize and say, okay, we'll make a half a million dollar effort here and there will be several universities involved in it, but we will raise each individual one somewhat in order to compromise on that issue of how much is enough. That's my recommendation.

Mr. BOUCHER. Let me get you to focus a bit, if you will, on the recommendation that we expect some degree of specialization at universities to an extent that it doesn't exist today. How valid is that as a guiding principle for the award of research grants? Dr. Wiley?

Dr. WILEY. That recommendation, putting it in terms of "The Fateful Choices" report is a recommendation to move toward the right on the institutional configuration diagram. And, quite frankly, that's the direction that I think universities are moving already. In many places around the country, departments are deciding that they have to reduce the number of areas of specialization within their discipline that they try to cover. Campuses as a whole are deciding to eliminate certain degree programs or departments or, in some cases, entire schools or colleges. Whether that's healthy or not is a different question, but that is a trend that's going on now. And it's perhaps one measure of the extent to which the system is right now underfunded.

Going to your earlier question and speaking as a research administrator at one of our research universities, I think the National Science Foundation has tried valiantly to stretch its limited funds by asking for more and more cost sharing from educational institutions, but that's—the days in which that can be accomplished are essentially over. We've identified and put forward literally every penny that universities have for institutional cost-sharing. If you look at the NSF's own statistics on the mix of research funding over the last 10 or 15 years, the largest increase is in own funds or institutional funds.

I don't know where anyone thinks that money will come from in the future. The only funds that we have really are tuition; state support in the cases of state schools, and that essentially is a tuition subsidy for the in-state students; gifts from alumni, which are normally targeted for specific purposes. We have very little in the way of unrestricted funds that can be used to support specific research projects.

So the cost-sharing that's available from institutions is a well that's dry, and I think that, although it wasn't stated explicitly as one of the reasons that the Commission called for fuller funding, if not full funding, of the projects that NSF deems worthy of supporting.

Mr. BOUCHER. You've noted that there's a trend underway now for universities to specialize to a greater degree and suggested that perhaps that's a product of the scarcity of dollars currently available for research, but you didn't tell me whether you think that's a healthy trend or not. Do you have any comment as to the merit or demerit of the fact that this specialization is now occurring?

Dr. WILEY. I think it carries both. There are some merits, some advantages and some disadvantages. One of the disadvantages that everyone should be aware of is that today, if you look around the country and ask, where are the strongest interdisciplinary programs flourishing, it's largely at the large, comprehensive universities where lots of different disciplines interact and mingle on a daily basis. That is what we sacrifice if we ask institutions to specialize. If the biologists and the physicists and the chemists and mathematicians and computer scientists aren't all present in large numbers and high quality in one institution, how will the future interdisciplinary interactions among them occur?

In "The Fateful Choices" report we suggested that they might still occur, perhaps at a slower pace, if we had an adequate infrastructure in telecommunications and computer links and video-teleconferencing, and so on. That's more a hope than a reality right now though.

Dr. NATHANS. May I comment?

Mr. BOUCHER. Dr. Nathans?

Dr. NATHANS. I don't think the PCAST members meant to imply that we ought to be, that universities ought to be eliminating major departments, major disciplines, but I think clearly they suggested that most universities, perhaps all universities, could not be comprehensive and they're going to have to make decisions primarily on the basis of merit, as to what programs ought to be emphasized. But I think you're certainly right, carried to extreme, I think that this would have pretty dire consequences.

Mr. BOUCHER. On the size of the research force?

Dr. NATHANS. No, I mean carried to extremes of, let's say, all biological sciences and no physical sciences, I mean that makes no sense, but I don't think certainly the PCAST members envisioned that sort of specialization.

Mr. BOUCHER. Do you agree that we are witnessing a trend now toward that specialization that's naturally occurring?

Dr. NATHANS. To some extent, yes.

Mr. BOUCHER. Should we as policymakers just observe that trend or should we do something to actively encourage it or should we discourage it in some respects?

Dr. NATHANS. I think we should certainly not encourage it to an extreme extent. I think what should be encouraged is building on strength.

Mr. BOUCHER. Dr. Stever?

Dr. STEVER. Well, I think this very last comment of Nathan's is very important. The history of NSF was growth of funds and they even had to go out to look for good researchers in some field and build fields, but—and that continued until sometime after Sputnik, but then suddenly the cornucopia growth of science and technology just had too many people applying and the first squeeze that was done was to keep the people employed but don't give them equipment and then don't give them the facilities, and pretty soon we had an immense backlog of needs there. And this is happening today.

The number of researchers clearly has a big effect on this. If the universities can't train as many researchers, the need is going to go down. But I do think we've got to keep the competition effect in there. That's probably the best way to force people into a new mode. Let competitive pressures choose where the good things are being done, as long as you have quality decisions in deciding which research projects should be granted.

Mr. BOUCHER. So I'm gathering from this panel that there's no general recommendation that the Federal research funding agencies insist upon a greater degree of specialization among universities as one way to address the problem that we have in terms of the proliferation of research grant applications and the frustration level that exists on campuses because fewer of them are being funded today, even with growing dollars. Dr. Nathans?

Dr. NATHANS. I don't think it's going to require that. I mean, I think the universities are already responding in the way that Dr. Stever mentioned.

Mr. BOUCHER. So the trend that is currently underway is enough? We shouldn't be imposing or suggesting that this become a measure by the research funding agencies or a standard that they apply?

Dr. NATHANS. Yes, I agree with that.

Mr. BOUCHER. Okay. Let me ask one other question, and then we'll conclude this morning. I'd like your comment on the general question that we addressed with the first panel about the need for research facilities funding. We have a $10 billion need. We are providing about $40 million annually through the National Science Foundation's competitive and merit review process, and we are providing something—and I just got this figure—of about $175 million every year in indirect cost funds to universities that is applied for research facilities. So we're approaching about a billion dollars annually in Federal monies that are applied to this need, somewhat less than that, but close to that.

And I'd like your sense of whether the overall amount of Federal dollars is sufficient? Is that about how much Federal money we ought to be applying to research facilities? And then I'd like your comments about how we might restructure the way that we're allocating these dollars. Most of it comes through earmarks. Would it be better to have the National Science Foundation, through its peer review processes, award most of this money, if not all of it? And do you have any other recommendations for us on the general question of how we as a Government go about meeting this $10 billion needs?

Dr. Stever?

Dr. STEVER. Let me shoot from the hip here. First of all, I think we do need more money in facilities. I would give one word of caution. There was a time, my time in the NSF, when a number of universities and their Congressmen, and so on, and supporters, came to us and said, "Look, we have this wonderful building that we have built in this area. Inside we have no equipment." That's a perfect way to build up a program larger and larger.

So as long as you get your new buildings in areas where they clearly have very good programs to operate, I think it's fine, but you've got to have competition there, too.

Mr. BOUCHER. What about the amount of money, the roughly $900 million to $1 billion we're spending every year. Is that enough? And if not, what is the right amount?

Dr. STEVER. I don't know, but almost everybody thinks of doubling this, as a way of answering your question on how much more bigger.

Mr. BOUCHER. Okay, Dr. Nathans?

Dr. NATHANS. I can't give you a figure, but it seems to me we need catch-up funds to bring facilities up to a certain level. And I must say what appeals to me in terms of continuing expenses for facilities and equipment is to do it through the indirect cost process, because that reflects the merit of a particular project because indirect costs, of course, come on the back of direct awards which have gone through the competitive process. And, of course, I don't mean to say that the catch-up grant should not also be through the competitive process.

Now the PCAST recommended in their report that there ought to be a three-year catch-up period in which there is shared funding, 50/50 funding, of research facilities and major equipment, and that all be done on a competitive basis, and, in fact, that any university that had accepted the earmarked route not be eligible for those grants. I think that's a pretty good idea.

Mr. BOUCHER. How would you award the funds on a competitive basis? Would you have the National Science Foundation's budget for facilities increased to meet that need?

Dr. NATHANS. Yes.

Mr. BOUCHER. Okay. Dr. Rushton?

Dr. RUSHTON. I'm—personally, I wouldn't be anxious to see a proliferation of new building, new laboratories in this country. I agree with Mr. Boehlert's position on that. We have, I think, a tremendous number of laboratories which are underutilized at this moment in time.

And I would prefer to see more money put into what I will call fix-it and recycle of what we have. I do believe that money is best placed in the hands of the NSF as a major portion of its budget, not a replacement for what it has, but in addition to what it has. So it would have certainly a very major say in how the monies are distributed and for what reasons.

It seems to me if we're $10 billion short at this moment in time, it seems to be a $10 billion project, that didn't occur overnight; it isn't going to be fixed overnight. I would suggest that we do have an accelerated program to do it. Maybe it's start off at pretty high rate and let inflation just peter it out for us. But it certainly is a major problem and it certainly has got to have, I think, a focused approach to it. I don't think it can be left to just a willy-nilly approach to letting the thing take care of itself. It is a national problem; there's no doubt about it.

Mr. BOUCHER. Okay, Dr. Wiley?

Dr. WILEY. Well, for one thing, I suspect that your $10 billion is very much on the low side. I think the problem is way bigger than that, just judging from—

Mr. BOUCHER. How big do you think it is?

Dr. WILEY. At least twice that, and there's nothing magic to doubling, but on my own campus the remodeling needs alone, if I translated, multiplied by the ratio of the number of Ph.D.s we produce—just off the top of my head, I don't have any other number to use, but multiply our needs by our fraction of the total, we would come up to more than $5 billion in just remodeling alone.

And I should point out that in some cases a remodeling project may actually be less well-advised or less cost-effective than simple demolition and building a new building. There is very little that you can do with a 75- or a 100-year-old building to bring it up to modern codes and standards for chemical and environmental safety, and so on. In many cases it's better simply to start over. So the entire issue of building and remodeling is one gets intermingled.

As far as the source of funds, certainly, along with everyone else who spoke today, I would support doing what we can to tap the funds that are currently being earmarked for this sort of thing and put them out competitively instead. I don't think anyone, at least of those that I meet with and speak with, would disagree with that.

Mr. BOUCHER. And do you agree that the National Science Foundation's facilities program is the right vehicle to distribute those funds?

Dr. WILEY. Well, I think the NSF facilities program should be enormously increased. Thirty-seven point five million, which is what they have out there for competition this year, is spit in the ocean. But all the agencies need to have building and facilities and equipment programs. I agree with what President Duderstadt said earlier on behalf of the Science Board, that it shouldn't be just an NSF program; they should have a building and facilities and equipment program that meets the needs of the researchers they sponsor, and so should the other agencies.

And I would point out, in particular, the Department of Agriculture has almost no competitive grants program and is the agency that gets a significant amount of the earmarking pressure. They need a competitive grants program and a competitive facilities program.

Mr. BOUCHER. Well, what would be wrong with just having the National Science Foundation perform that function for all the agencies? We've heard the recommendation from NSF's Commission on the future of the agency, that it ought to perform that function for strategy planning across the Government, at least making the recommendations. Why not simply allow the NSF, through its facilities program, to meet the building needs?

Dr. WILEY. Well, the NSF has very little in its portfolio for things like agricultural research, just to name one example. I mentioned the Department of Agriculture. I suspect that they would not be in the best position to judge where the needs are in that area. And there are a number of others that aren't as strongly represented in the NSF portfolio. But compared with what we have today—

Mr. BOUCHER. But, in theory—

Dr. WILEY. —it would be marvelous.

Mr. BOUCHER. —the Science Board has people who have that expertise.

Dr. WILEY. Yes.

Mr. BOUCHER. It's very broad-based in its structure.

Any other comments on that question?

[No response.]

Well, we could talk for a long time. I've got a lot of other questions, but I'm going to defer those until a later date. The subcommittee will be continuing this inquiry and we will seek the advice of each of you as that process matures. And I would offer to you the opportunity to contact us, share additional ideas with us that you have. When you read about other comments that witnesses have made in the course of these hearings, and you want to respond to that, please feel free to do so. We would welcome your continued advice.

And, with the subcommittee's thanks, we will dismiss you now and adjourn this hearing.

[Whereupon, at 12:00 noon, the subcommittee adjourned subject to the call of the Chair.]

APPENDIXES

Fateful Choices

The Future of the U.S. Academic Research Enterprise

A Discussion Paper

GOVERNMENT-UNIVERSITY-INDUSTRY RESEARCH ROUNDTABLE

National Academy Press
Washington, D.C. 1992

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.

Library of Congress Catalog Card Number 92-60536

International Standard Book Number 0-309-04643-4

S 485

Printed in the United States of America

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ACKNOWLEDGMENTS

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]

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[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 workforce, 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 Roundtable, *The Future of the U.S. Academic Research Enterprise: Report of a Conference*, Washington, D.C.: National Academy Press, March 1992.

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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.

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.

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.

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

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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.

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.

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 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

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

NEW COMMUNICATION NETWORKS

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.

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AN EXPANDED ROLE FOR ACADEMIC RESEARCH

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.

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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

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.

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.

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.

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.

CLARIFYING FUNDING RESPONSIBILITIES

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.)

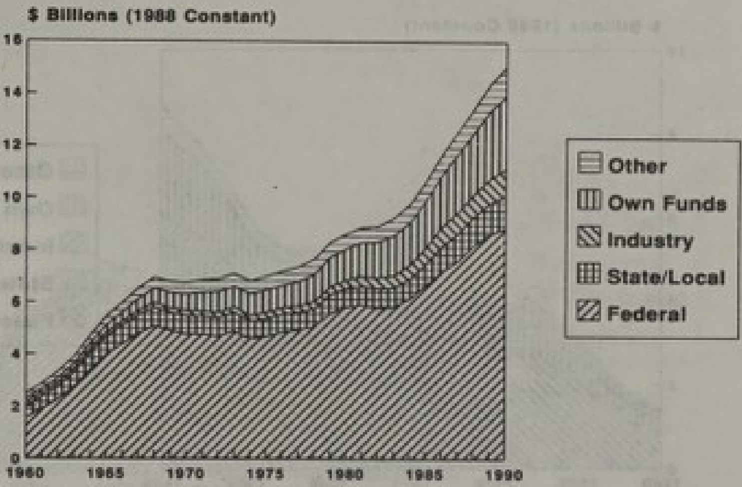
Policymakers need to rethink the current division of federal-state and federal-university responsibilities for higher education in general and research in particular. This will require more effective ongoing communication, interaction, and coordination among research sponsors and academic institutions.[7]

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



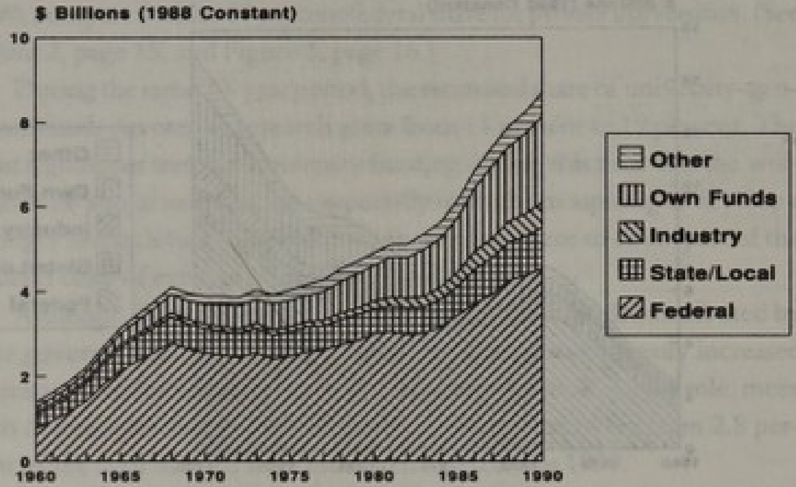
NOTE: Data series within the figures are not overlapped; top line represents total. Financial data are expressed in 1988 constant dollars to reflect real long-term growth trends.

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 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 2

Public Doctoral Institution R&D Expenditures by Source of Funds



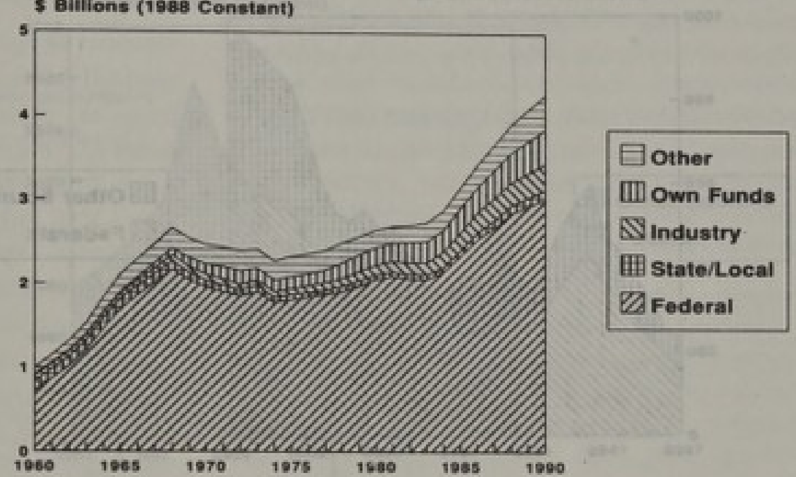
NOTE: Data series within the figures are not overlapped; top line represents total. Financial data are expressed in 1988 constant dollars to reflect real long-term growth trends.

DEFINITION OF TERMS: Public doctoral institutions are institutions that have granted an average of 10 or more Ph.D. degrees per year in 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 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.

FIGURE 3

Private Doctoral Institution R&D Expenditures by Source of Funds



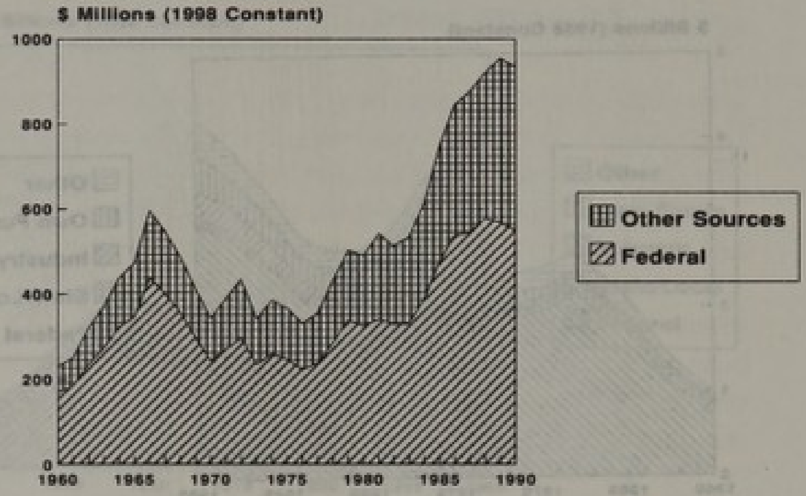
NOTE: Data series within the figures are not overlapped; top line represents total. Financial data are expressed in 1988 constant dollars to reflect real long-term growth trends.

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.

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 in 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 indirect 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.

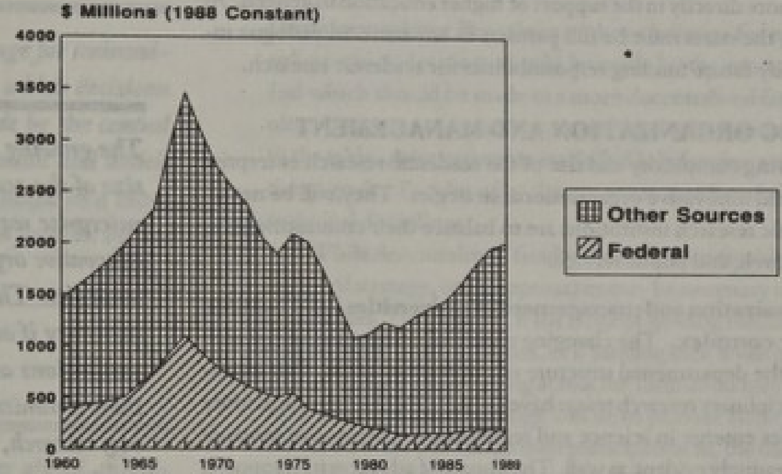
SOURCE: National Science Foundation, Division of Policy Research and Analysis. Database: CASPAR. Some of the data within this database are estimates, incorporated where there are discontinuities within data series or gaps in data collection. Primary data source: National Science Foundation, Division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

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 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 con-tant 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 in 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 research 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 money 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 results, 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.

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.

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 circumstances, 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

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 decisionmaking 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.

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.

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

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.

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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 redirected 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.

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.

. . . 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.

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 academic 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 blocs 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.

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.

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.

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.

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.

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

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

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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

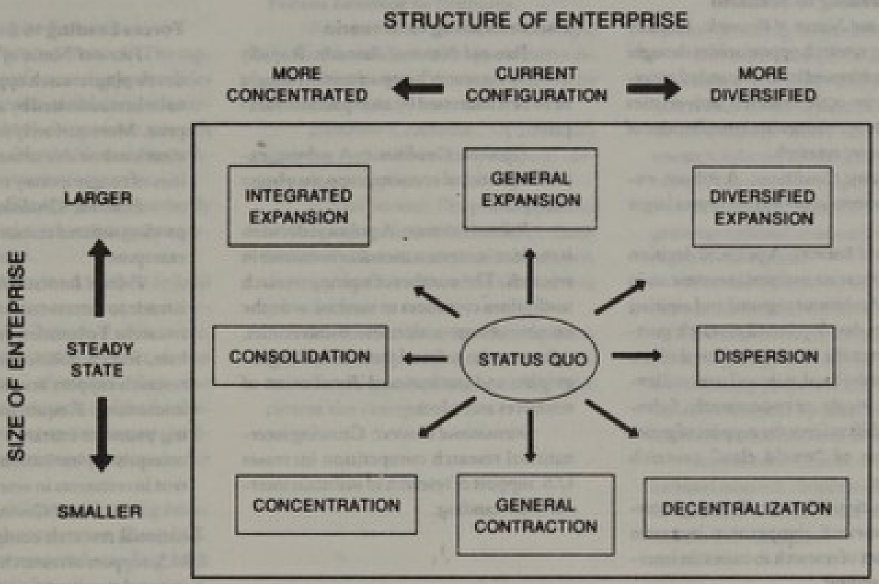


TABLE 1

Expansion Scenarios

INTEGRATED EXPANSION

A larger enterprise, in both numbers of researchers and active departments, within universities with broad research portfolios.

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.

Economic Conditions: A robust, expanding national economy supports a larger enterprise.

Political Interests: A political decision is made to increase 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.

International Context: Growing international research competition increases U.S. support of research to maintain international standing.

GENERAL EXPANSION

A larger enterprise, in both numbers of researchers and active departments, with comparable increases in both large-scale universities and aspiring research institutions.

Forces Leading to Scenario

Pace and Nature of Research: Rapidly developing research opportunities thought to be best addressed by an expanded enterprise.

Economic Conditions: A robust, expanding national economy supports a larger enterprise.

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.

International Context: Growing international research competition increases U.S. support of research to maintain international standing.

DIVERSIFIED EXPANSION

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

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.

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.

TABLE 2
Steady-State Scenarios

CONSOLIDATION

An enterprise of the current size, in both numbers of researchers and active departments, increasingly concentrated within universities with broad research portfolios.

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.

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.

International Context: Growing international research cooperation allows U.S. to maintain international standing with current size enterprise.

STATUS QUO

An enterprise of the current size, in both numbers of researchers and active departments, within the current configuration of research institutions.

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.

Economic Conditions: A modestly growing national economy supports current size 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.

International Context: Growing international research cooperation allows U.S. to maintain international standing with current size enterprise.

DISPERSION

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

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.

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.

TABLE 3
Down-Sizing Scenarios

CONCENTRATION

A smaller enterprise, in both number of researchers and active departments, concentrated within universities with broad research portfolios.

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 the current enterprise.

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.

GENERAL CONTRACTION

A smaller enterprise, in both numbers of researchers and active departments, with comparable decreases in both large-scale universities and aspiring institutions.

Forces Leading to Scenario

Economic Conditions: A weakened national economy no longer is able to support an enterprise of the current size.

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.

International Context: Growing global research system, with open access across borders, allows U.S. to target selected fields of vital strategic interest.

DECENTRALIZATION

A smaller enterprise, in both numbers of researchers and active departments, distributed across institutions with more narrowly focused research portfolios.

Forces Leading to Scenario

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 an enterprise of the current size.

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.

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 activities 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 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.

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.

POLICY REQUIREMENTS

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.)

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

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

FIGURE 7

Scenario Policy Requirements

STRUCTURE OF ENTERPRISE

SIZE OF ENTEPRISE	MORE CONCENTRATED ←	CURRENT CONFIGURATION	→ MORE DIVERSIFIED
LARGER ↑	Significant increase in S&E personnel High real annual growth rate in research funding Decentralized decisionmaking	Significant increase in S&E personnel High real annual growth rate in research funding	Significant increase in S&E personnel High real annual growth rate in research funding Communications infrastructure
STEADY STATE	Replacement of S&E talent Moderate real annual growth rate in research funding Decentralized decisionmaking	Replacement of S&E talent Moderate real annual growth rate in research funding	Replacement of S&E talent Moderate real annual growth rate in research funding More centralized national decisionmaking Communications infrastructure
↓ SMALLER	Sustained research funding no less than current levels More centralized national decisionmaking Open access to foreign science and technology	Sustained research funding no less than current levels More centralized national decisionmaking Open access to foreign science and technology	Sustained research funding no less than current levels Centralized decisionmaking Communications infrastructure Open access to foreign science and technology

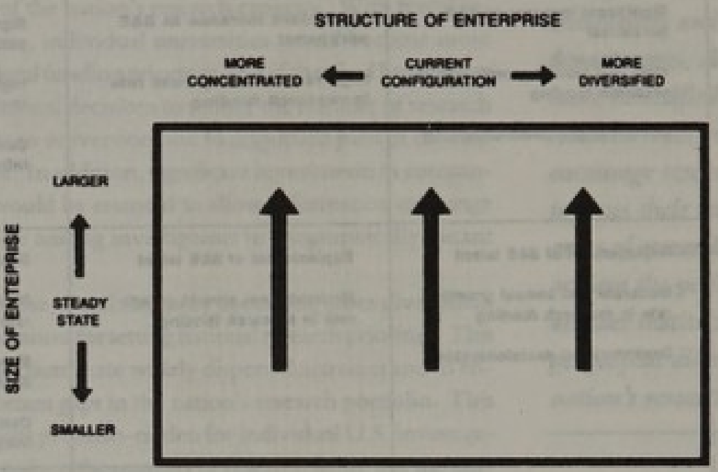
structure of the enterprise is more concentrated or more diversified. (See Figure 8, page 41.)

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 precollege 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

FIGURE 8

Human Resource Requirements



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

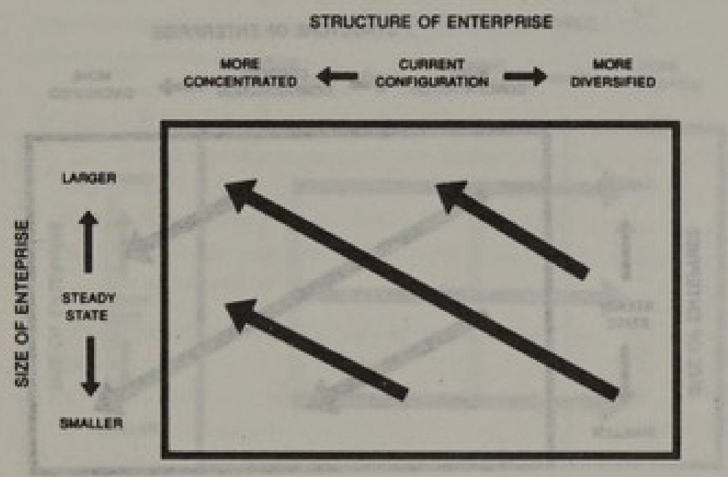
The second source of talent would be the potentially large number of foreign-trained scientists and engineers desiring to work in American research institutions. However, reliance on this source is risky. As described earlier, other countries, including many developing nations, are creating their own 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.

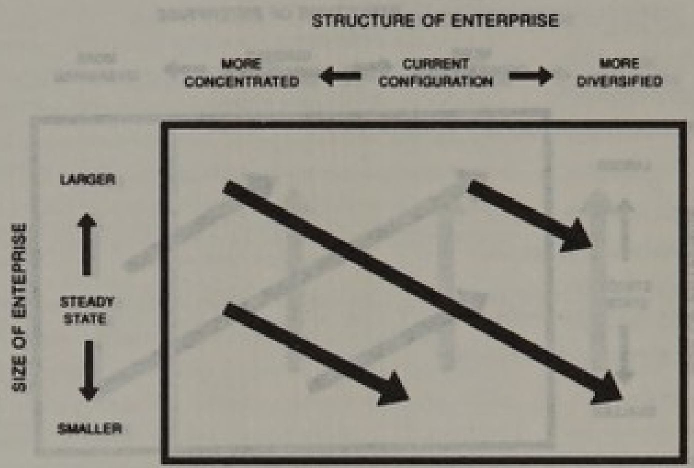
Locus of Decisionmaking

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-

FIGURE 10
Shift Toward National Decisionmaking



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

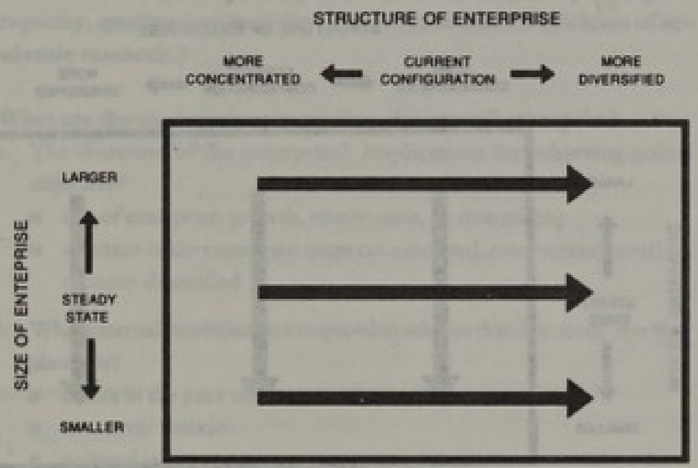
In an enterprise comprised of more research institutions with limited research portfolios, there also would be greater need for decisionmaking at the level of the central administration of each institution. If these universities were to reduce the number of their research fields, more centralized decisionmaking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

FIGURE 11
Requirements for Communication Technologies



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

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.

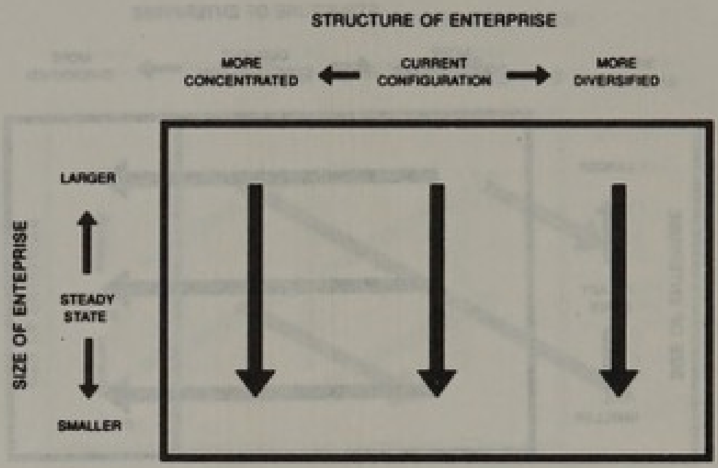
If the U.S. enterprise were to shrink over the next several decades, access to foreign research would become absolutely essential for maintaining the overall quality and usefulness of academic research in this country. (See Figure 12, page 45.) In this situation, the United States would have to have 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 decisionmaking, communication infrastructure, and openness of the global research system. The proposals must be evaluated in terms of their explicit and im-

FIGURE 12

Required Access to Foreign Research



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.

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.

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.

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

STRATEGIC OPTIONS

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

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.

The changing politics of research and the nature of the choices to be made demand new approaches to decisionmaking.

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.

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.

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

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 become 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.

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.

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-

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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.

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 decisionmaking 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. 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.

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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.

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.

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

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.

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AIR PRODUCTS

4 March 1993

The Honorable Rick Boucher
Chairman
Subcommittee on Science
Committee on Science, Space, and Technology
Suite 2320
Rayburn House Office Building
Washington, DC 20515-6301

Dear Mr. Boucher:

Subject: U.S. House of Representatives
Subcommittee on Science
Commission on the Future of the National Science Foundation (N.S.F.)

One question that your Committee asked of Panel I during our testimony was relating to improving our grades K through 12 education--particularly in science and math. I, unfortunately, did not have the opportunity to comment on this issue.

I believe a very practical way to upgrade the teaching skill banks of our primary and secondary schools is for the government to entice retired scientists and engineers to become "adjunct teachers" in our schools. Funds could be set aside (perhaps in the N.S.F. or at the state level) to be dispensed to the nation's schools to pay for this considerable and obviously scarce expertise. However, I believe President Clinton would have to give these retirees relief from anticipated double taxation by allowing a credit against Social Security taxes. This approach would put a true "technological policy" into play early in the educational pipeline. I am certain that this is not a novel concept, however, "good ideas don't care where they come from."

In closing, let me assure you that I found my day of testifying to be extremely worthwhile. I was impressed and pleased by the thoughtful interest and in-depth questioning that took place. If I can be of further assistance, please let me know.

Sincerely,

Brian M. Rushton

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ISBN 0-16-040759-1
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