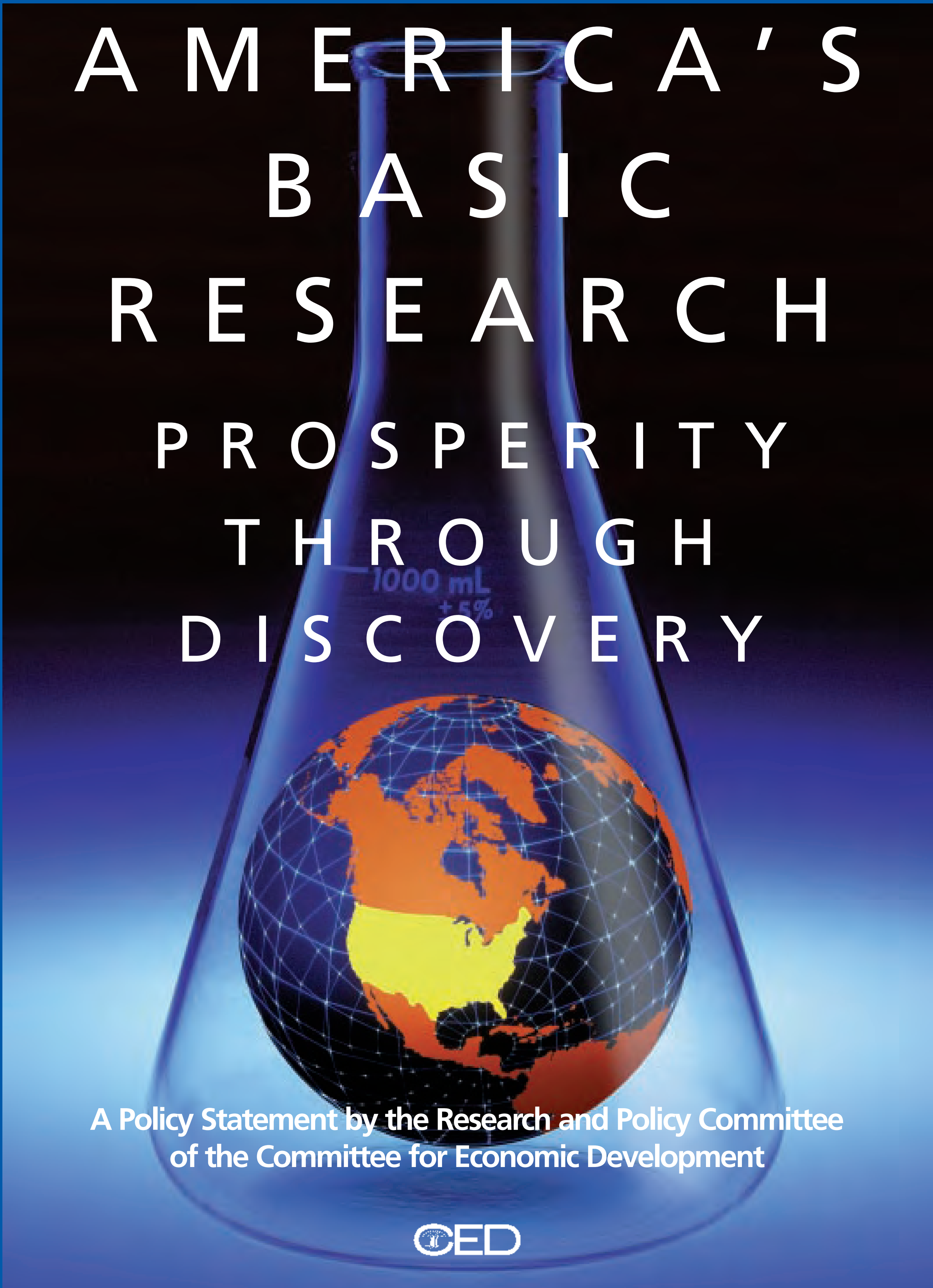
AMERICA'S BASIC RESEARCH

PROSPERITY THROUGH DISCOVERY



A Policy Statement by the Research and Policy Committee
of the Committee for Economic Development

CED

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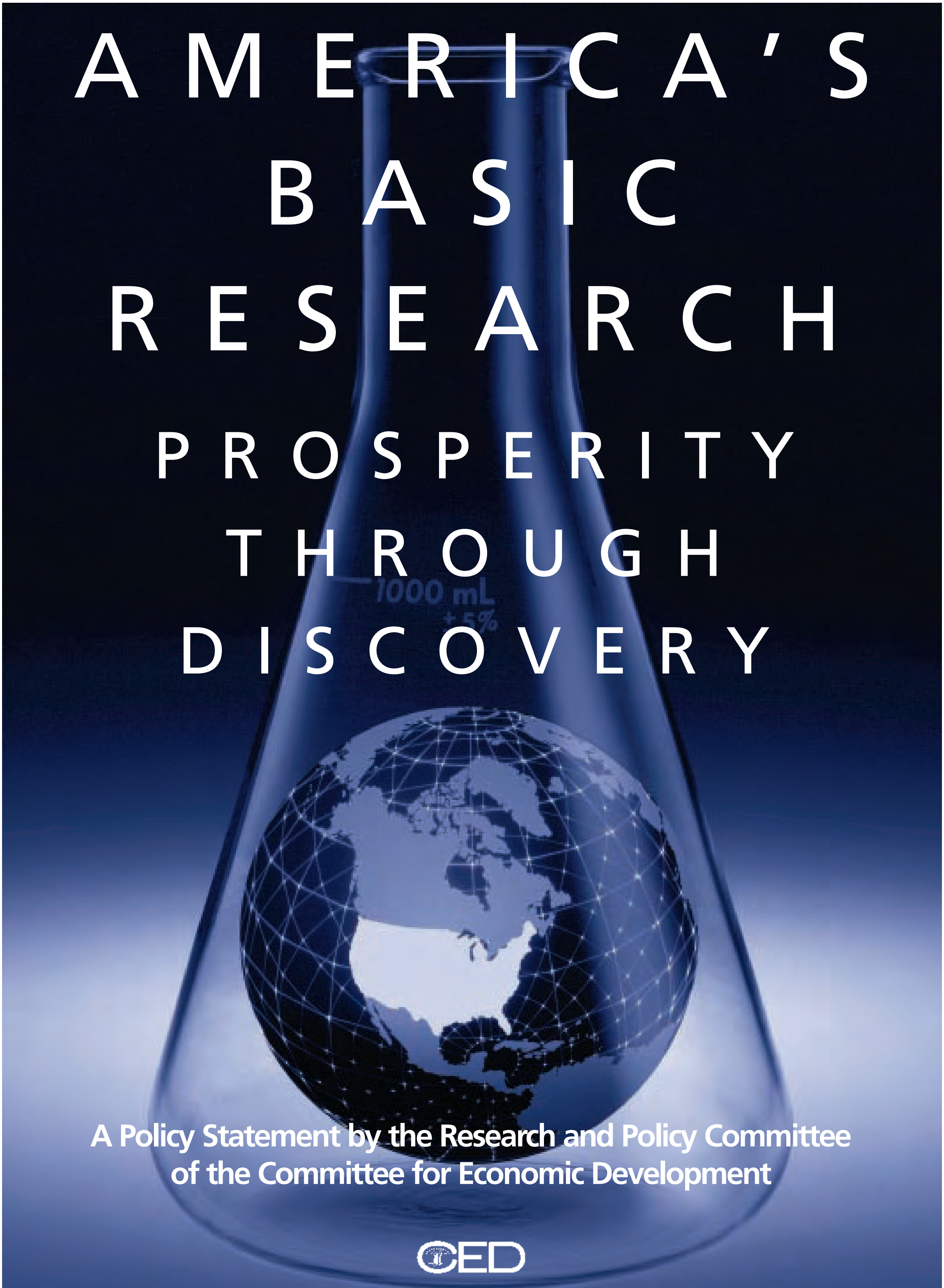

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Library of Congress Cataloging-in-Publication Data

Committee for Economic Development. Research and Policy Committee.
America's basic research : prosperity through discovery : a policy statement / by the Research and Policy Committee of the Committee for Economic Development.

p. cm.

Includes bibliographical references
ISBN 0-87186-130-5
1. Research—Economic aspects—United States. 2. Research—United States.

HC110.R4C63 1998
001.4'0973—dc21 98-24814
CIP

First Printing in bound book form: 1998
Paperback: $18.00
Printed in the United States of America

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AMERICA'S BASIC RESEARCH

PROSPERITY THROUGH DISCOVERY

RESPONSIBILITY FOR CED STATEMENTS ON NATIONAL POLICY

The Committee for Economic Development is an independent research and policy organization of some 250 business leaders and educators. CED is nonprofit, nonpartisan, and nonpolitical. Its purpose is to propose policies that bring about steady economic growth at high employment and reasonably stable prices, increased productivity and living standards, greater and more equal opportunity for every citizen, and an improved quality of life for all.

All CED policy recommendations must have the approval of trustees on the Research and Policy Committee. This committee is directed under the bylaws, which emphasize that "all research is to be thoroughly objective in character, and the approach in each instance is to be from the standpoint of the general welfare and not from that of any special political or economic group." The committee is aided by a Research Advisory Board of leading social scientists and by a small permanent professional staff.

The Research and Policy Committee does not attempt to pass judgment on any pending specific legislative proposals; its purpose is to urge careful consideration of the objectives set forth in this statement and of the best means of accomplishing those objectives.

Each statement is preceded by extensive discussions, meetings, and exchange of memoranda. The research is undertaken by a subcommittee, assisted by advisors chosen for their competence in the field under study.

The full Research and Policy Committee participates in the drafting of recommendations. Likewise, the Trustees on the drafting subcommittee vote to approve or disapprove a policy statement, and they share with the Research and Policy Committee the privilege of submitting individual comments for publication.

Except for the members of the Research and Policy Committee and the responsible subcommittee, the recommendations presented herein are not necessarily endorsed by other trustees or by the advisors, contributors, staff members, or others associated with CED.

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*Voted to approve this statement but submitted memorandum of comment, reservation, or dissent, see page 80.

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PURPOSE OF THIS STATEMENT

Basic research is a critically important—yet often undervalued—source of American economic growth and prosperity. Advances in fundamental science and engineering knowledge resulting from basic research have made possible most of our recent technological progress and the resulting improvements in incomes and quality of life. Our nation now invests a mere 0.4 percent of Gross National Product on basic research.

As this policy statement is being released, American science and scientists are acknowledged as preeminent in the world. Many of our scientific endeavors do receive significant political, public, and financial support. But competing demands for scarcer federal dollars, shifting economic and social priorities, political pressures, and short-term corporate earnings pressures pose long-term threats to the continued strength of America's basic research and its contributions to our prosperity.

This policy statement takes a broad look at America's basic research enterprise and lays out the processes and systematic reforms needed to meet emerging risks to the valuable outcomes from our investments in basic research. CED's Trustees undertook this important project in the firm belief that significant progress with many of society's problems and new discoveries will primarily depend upon fundamental scientific insights derived from basic research.

ACKNOWLEDGMENTS

This policy statement was developed by an outstanding group of business and academic leaders from some of the nation's top research-oriented companies and research universities. The breadth and depth of experience represented in this working group is extraordinary, and we are very grateful for the time, effort, and care each member put into the development of this statement. We are also grateful for the attention given to this report by numerous scholars, advisors, and reviewers.

Special thanks goes to subcommittee chairman, George H. Conrades, Executive Vice President, GTE and President of GTE Internetworking, for his leadership and for the intellectual rigor and drive he brought to this project. Thanks are also due to subcommittee members Raymond V. Gilmartin, Chairman, President & CEO of Merck & Co., Inc., for his strong personal commitment to this project and to Christopher D. Earl, Senior Vice President of Perseus Capital LLC, for his help in crafting the introductory chapter of this report. The clear, cogent, and perceptive analysis in this statement is due in large part to our co-project directors, William J. Beeman, CED's Vice President and Director of Economic Studies, and CED's Senior Economist Scott Morris, who added immeasurably to the success of this study. Thanks also to Amanda Turner in CED's Washington office for her assistance on this project.

We are also grateful to The New York Community Trust for supporting this project.

Josh S. Weston
Chairman
CED Research and Policy Committee
Honorary Chairman
Automatic Data Processing, Inc.

Chapter 1

INTRODUCTION AND SUMMARY OF FINDINGS AND RECOMMENDATIONS

Asked why American scientists have won so many Nobel prizes, a former secretary-general of the Royal Swedish Academy of Sciences once remarked, "No other country has invested as much money in research over the years as the U.S. It's as simple as that." Indeed, America's long-standing endowment of basic research has been overwhelmingly successful, providing American society not only with the fruits of new knowledge, but also with the practical benefits of economic growth and improvements in the welfare of its citizens.

CED believes, however, that the success of American basic research is not simply a matter of money. Rather, as we argue in this report, that success has grown from a uniquely American organization of the basic research enterprise. That organization has relied on an abiding faith in the superiority of a free market in ideas and entrepreneurial competition over top-down decision-making in ensuring the quality and efficiency of research efforts.

We believe it is essential to uphold the integral role of government in supporting basic research, as industry continues to focus on R&D with specific product-directed goals. The large economic returns from investments in basic research show it to be an extremely productive use of the taxpayer's money. We are encouraged by recent bi-partisan proposals to increase the nation's investment in basic research. But we cannot take today's political support for granted, especially as we look towards a future of greater resource constraints. American excellence in basic research is truly a national treasure, but its supporters must be vigorous and articulate in its defense.

Basic research—conducted in academic institutions, federal laboratories, private companies, and nonprofit research institutions—has provided the intellectual and technological foundation for innumerable practical inventions that are integral to American technological and economic leadership. Industries as diverse as pharmaceuticals, defense, electronics, and aerospace have relied on basic discoveries fueled by government grants.

A critical factor in the translation of basic research into functional applications has been America's unique entrepreneurial spirit. From small start-ups to large multinational corporations, American ingenuity has excelled in converting new knowledge into practical and profitable products. A common misconception is that fundamental research is conducted in an ivory tower, with no regard for practical benefits. On the contrary, a consistent virtue of U.S. basic research has been the pursuit of fundamental knowledge with a sharp eye out for downstream applications. American entrepreneurs have been distinguished by their ability to capitalize effectively on new knowledge wherever it arises.

Like any far-reaching enterprise that comprises hundreds of institutions and thousands of workers, America's basic research establishment must constantly renew itself in response to changing conditions in global economic, political, and scientific markets. This enterprise must also recognize the legitimate expectations of the society that supports its efforts.

The basic research enterprise faces important questions about the priorities and balance of its basic research missions, the consistency of government support, the global dissemination of new knowledge, and the collapse of Cold War rationales for massive investment in defense research. At the same time, the institutions that perform basic research must maintain the exceptional quality of their faculties, grapple with ever-increasing costs, and confront the complex challenges of the expanding ties between corporations and universities.

The goals of this report are first, to set forth the compelling case for basic research and its benefits to society, and second, to make recommendations to policymakers and practitioners. We endorse the strength of American university-based research and its tradition of excellence. But we also advocate a ceaseless quest to measure output against investment, and results against expectations. This means extending the use of peer review and competition for research grants. We argue for an end to political earmarks for research, and we are concerned about "mission creep" in those sectors of the basic research establishment—particularly certain of the Department of Energy's national laboratories—that have completed or lost their mandates. In this regard, we are concerned about the growing tendency of government to directly fund the development and commercialization of technologies which, with few exceptions, is properly the function of the private sector.

This report also reaffirms positions taken in previous CED policy statements that have special relevance to basic research. We place great emphasis on improving K-12 education to ensure our future supply of outstanding scientists. We also insist on the importance of curbing federal entitlement spending, so that future investments in basic research will not be undermined by the budgetary effects of inexorable demographic pressures.

We take the long view: Although a few scientific breakthroughs find immediate applications, yields on basic research are typically realized far in the future. Frequently the greatest benefits are the least anticipated. The virus research initiated by the War on Cancer in the 1970s delivered its most significant benefits—both unintended and unexpected—in the treatment of AIDS in the 1990s; only now is this research yielding new drugs that will transform clinical oncology in the 2000's.

The medical, environmental, social and military challenges of the 21st century will demand solutions that can only emerge from a healthy and productive basic research system. CED firmly believes that maintaining excellence in basic research is essential to America's continued prosperity and global leadership.

FINDINGS

1. Basic research in science and engineering has made a major contribution to the growth of the U.S. economy. Economic returns on investments in basic research are very high. In addition, the returns to the nation from basic research investments are substantially higher than the returns to private firms, since advances in fundamental knowledge tend to be widely dispersed and exploited in innovations that deliver substantial economic benefits over a lengthy period.

2. Basic research performed in major research universities is typically correlated with strong economic activities in their neighboring locales. For example, there are more than 1,000 MIT-related companies in Massachusetts, with world wide sales of more than $53 billion. Similar developments have taken place in California's Silicon Valley and the Research Triangle of North Carolina.

3. The federal government has long been the most important source of support for basic research. Government funding of basic research exceeds that of private industry in both absolute amount and as a share of its total R&D activities. Of the nearly $63 billion that government spends on R&D annually, $18 billion goes to basic research, while just $8 billion of industry's total R&D spending of $133 billion does so. However, the long-

term future of federal funding is clouded by the likely budgetary effects of impending demographic pressures.

4. Publicly-funded basic research is critical to private sector innovation. Although private industry conducts basic research, these efforts are primarily to "fill-in-the-gaps" within broader programs of applied research aimed at new product development. Industry depends on the intellectual foundations provided by basic researchers in the nonprofit and public sectors for innovative products and services. A recent study found that 73 percent of research publications cited by industrial patents were derived from government-funded research.

5. American science is not conducted in an "ivory tower." Even basic researchers who are exploring fundamental problems of theoretical physics, advanced materials, or molecular biology are doing so with the expectation that their work will be relevant to the development of new chips, composite aircraft, or cancer drugs.

6. Federal funding is directed principally not to institutions, but to individual investigators who compete directly for government grants. These investigators represent the backbone of the American basic research enterprise. An essential strength of the American basic research system is the allocation of grants through a rigorous and competitive peer review process.

7. The most important American institutions conducting basic research are the nation's 200 major research universities. These institutions are characterized by highly competitive allocation of funds, a tradition of excellence, and a brain trust of highly trained and motivated faculty, post-doctoral fellows, and graduate students. The wide, unrestricted dissemination of research results has been important to the broad benefits of university-based basic research for our society.

8. Passage of the Bayh-Dole Act in 1980 explicitly allowed recipients of government grants to retain title to inventions made using government funds. This law has stimulated intense growth in university patenting and subsequent technology transfer from basic research institutions to industry. As a result, industry is increasingly involved in collaboration with, and sponsorship of, university-based researchers. While certain fields are comparatively untouched by Bayh-Dole, the biotechnology industry in particular has been a major beneficiary.

9. When managed skillfully, university-industry relationships can benefit both the research institutions and companies, while society reaps rewards from the efficient transfer of technology into useful products. CED believes, however, that these relationships should be conducted according to guidelines that protect the primary basic research mission of the universities.

10. The priorities of the federal government are changing. With the end of the Cold War, Pentagon requirements for basic research have shifted and contracted. As a result, the missions of the massive federal laboratory system have changed, and in some cases, disappeared. The federal laboratories continue to play important roles in defense, health, and energy. But some, particularly among the national laboratories at the Department of Energy, have not acted forcefully to eliminate work in areas no longer relevant to their missions, nor to expose themselves to merit-based peer review processes.

11. Deficiencies in science teaching in primary and secondary education threaten our future supply of outstanding young researchers. These deficiencies may also limit the capacity of women and minorities to pursue careers in basic research. Moreover, continued societal support for basic research depends on an informed electorate who recognize the benefits of a strong basic research system.

12. As other nations build their economic strength, they will inevitably also invest

in basic research capabilities. While the United States continues to be the world's leader in the generation of new knowledge, other countries are contributing more than in the past. We have nothing to fear from these trends. So long as basic research is freely disseminated around the globe and the U.S. continues to capitalize on the practical application of new knowledge, global expansion of basic research on balance will benefit the U.S. economy and society at large.

SUMMARY OF RECOMMENDATIONS

1. Policymakers in Congress and the Administration, informed by a national policy debate, should set broad national priorities for basic research that reflect the needs of society at large. Scientists have an important role to play in informing the debate, but such priorities are appropriately set by our accountable, elected political leaders.

2. Federal support for basic research should continue to be diverse in its sources and objectives. Efforts to impose central control or to concentrate resources in a single research area should be resisted.

3. Within the broad priorities established by policymakers, the primary mechanisms for allocating federal basic research funds in all agencies and to all institutions should be based on scientific merit determined through peer review. In general, support should be given to individuals and not to institutions. Political earmarks for basic research are an unproductive use of scarce resources.

4. Because federal support is essential for a thriving basic research enterprise, the long-term federal budget outlook is critical. Basic research should be a high priority in the federal budget in the decades to come. This will require reforms of the federal entitlement programs that otherwise will grow explosively in response to demographic pressures a few years hence.

5. The most productive recipients of federal basic research funds are the nation's research universities. Their leadership and productivity should continue to be a guide for other institutions receiving federal support.

6. Individual investigators are increasingly weighed down by the complex demands of seeking grant support. Mechanisms should be devised to allow researchers to compete for longer-term funding, and administrative burdens from granting agencies should be reduced.

7. Funding agencies are increasingly attempting to reduce payments for indirect costs and to shift costs to research institutions. We recommend reform of the system for determining indirect costs to ensure simplicity, fairness, and reductions in the costs of compliance.

8. CED calls on Congress and the Administration to clearly determine the missions of the Department of Energy's national laboratories and decide what realignments of missions and functions are necessary. The activities of the national labs must be justified on the basis of strong missions, peer-reviewed determinations of scientific merit, and efficient structures for management and oversight.

9. With few exceptions, government should not be in the business of directly funding the development and commercialization of technologies, which is properly a function of the private sector. Exceptions generally occur in cases where the funding serves a clear procurement function for government missions, such as defense technology needs.

10. The federal government should continue to play a major role in funding large-scale infrastructure projects that are used extensively by many researchers, such as experimental energy generation facilities and the Hubble Space Telescope.

11. As CED has recommended in previous reports, the United States must raise academic achievement in math and science in grades K-12. To improve learning in math and science, we urge the adoption of national standards, policies to increase teacher knowledge and skills, and upgrades in classroom curricula, facilities, and teaching materials.

12. The training of graduate students is an indispensable role of the research universities. The federal government should make graduate student training a higher priority and increase its funding of scholarships and training grants. Research universities should explore ways to reduce the time and expense required to obtain a doctorate. Since a majority of Ph.D. graduates will not return to the research universities as faculty, graduate schools should offer training programs and mentorships to prepare their students for employment outside of academe.

13. Industry-university relations and university patenting and licensing should be directed towards maximizing benefits for the society at large. As a general principle, new knowledge from university basic research should be freely disseminated. In cases where new knowledge has commercial potential, however, patenting and licensing may be appropriate and in the public interest. However, these technology transfer activities should not dilute or compromise the basic educational and research missions of the university.

14. The United States should expand its efforts to benefit from international collaboration and the globalization of basic research. To this end, public and private policies should ensure that the United States is an attractive place for researchers to live and work. Our immigration policies should be further liberalized to allow foreign scientists and engineers more long-term and permanent visas as well as more short-term visits to act as consultants, collaborators, and visiting scholars.*

*See memorandum by James Q. Riordan, page 80.

UNDERSTANDING THE CONTRIBUTION OF BASIC RESEARCH

America's basic research is one of the nation's greatest assets. Advances in fundamental science and engineering derived from basic research, combined with strong economic incentives for technological change and innovation, have made an enormous contribution to the economic prosperity and social progress enjoyed by U.S. citizens. Achievements in basic science and engineering have also contributed to our nation's role as economic, social, political, and military leader, which has helped bring about an historically unique period of relative peace and stability in the world. **It is clearly in the national interest to maintain and to strengthen America's commitment to basic research and to improve the productivity of resources used in basic research.**

As in the past, the economic prosperity of future generations will depend critically on present day efforts to sustain this country's historic and fundamental commitment to basic research. Indeed, this commitment is a tremendous source of hope for the future; the solutions to many of society's greatest challenges and the key to exploiting new opportunities—such as the cure for cancer and AIDS, unlocking new productive potential from natural and man-made resources, and the antidote to looming environmental concerns like global warming—will depend upon fundamental scientific insights derived from today's basic research.

It is important that policymakers and the public understand the benefits of basic research. Without an appreciation of these benefits, it will be difficult to maintain our national commitment to the basic research enterprise, and thus maintain our nation's leadership in the future.

THE BENEFITS OF BASIC RESEARCH

Although basic research—experimental or theoretical work undertaken to add to the knowledge of fundamental science and engineering—accounts for only 15 percent of total R&D in the United States, it has been a major factor in the improvement of technologies, living standards, and life styles. For non-scientists, the contribution of basic research may not be obvious because of the complicated "trail" between research, discovery, and innovation. One reason the trail is complicated is that fundamental knowledge derived from basic research is generally widely shared and often exploited by scientists and entrepreneurs who were not involved in the original discovery. Moreover, the potential value of new discoveries from basic research may not be immediately evident even to the discoverers and consequently the associated innovations often occur several decades after the initial discovery. By contrast, there may be only a few months or years between applied and development research and commercial innovations. (For definitions of basic, applied, and development research see Box 1, page 7.) Consequently, the results of applied research can easily be observed in new or improved products and processes introduced by the business firms that sponsored the research. Of course, basic, applied, and devel-

BOX 1

CHARACTERISTICS OF RESEARCH AND THE DISCOVERY PROCESS

Traditional Definitions

Scientists and R&D sponsors have traditionally divided R&D activities into three categories: basic, applied, and development research. Although it is often difficult to place a specific research project exclusively in one of these categories, the data on R&D activity published by the federal government continue to follow this division. These three categories may be described as follows:

- **Basic research** is experimental or theoretical work undertaken to add to fundamental science and engineering knowledge. This knowledge is often drawn upon in subsequent basic or applied research. Although basic research can be exploratory, without any particular application in mind, the vast majority of basic research is directed toward achieving new science or engineering knowledge in areas of interest to funders.
- **Applied research** includes investigations that draw from basic research or other applied research to create new knowledge that in turn can be used to develop new or improved products and processes.
- **Development research** draws on existing knowledge gained from basic and applied research and from practical experience for the purpose of creating innovative new products or processes, as well as incremental improvements for existing products or processes.

The Discovery Process and Alternative Definitions

Despite the traditional distinctions and boundaries between basic, applied, and development research, it would be a mistake to draw the conclusion that the best description of the discovery and innovation process is a linear model which begins with basic research, proceeds to applied research and ends in development. Discovery and innovation often do not proceed in such a sequential and uni-directional fashion.

Analysis of individual cases demonstrates that technological advances occur in an interactive, interwoven process where breakthroughs take place both before and after basic research. There are numerous examples of technological breakthroughs occurring well before the basic science was understood (see bullet on "Xerography" page 9). This interactive discovery and innovation process—often described as a "chain link" or "continuous" model incorporating feedback loops—appears to be more characteristic of the R&D process than the linear model.

Given this deeper understanding of the discovery process, and its rejection of a linear model, characteristics other than the traditional definitions have been proposed to delineate basic research. For example, it has been suggested that the time period between research and its effects on output is one useful point of distinction. There have been many instances where a long period—often 10 to 20 years—has elapsed before new knowledge derived from basic research had any influence on output. However, there are also cases where the time lapse between basic research and innovation is very short. Moreover, many business firms have recently instituted reforms in the research process designed to shorten this time lag.

An additional distinction between basic and applied research is based upon the extent to which the results are shared with others. Fundamental knowledge tends to be widely shared, because, unlike most products, its use by another individual does not reduce its availability to those who made the discovery (see Box 2, page 12). By contrast, the dispersion of the results of applied research is generally more circumscribed by patents or secrecy so that the fruits of discovery can accrue to the firms sponsoring the research.

The Myth of Untargeted and Unmanageable Research

Perhaps because individual discoveries are often serendipitous and the discovery process

Continued on page 8

Continued from page 7

itself is inherently complex, it is sometimes assumed that basic research cannot be targeted toward objectives or managed effectively. But in fact, R&D investments, including basic research, can be and generally are, carefully managed and directed to achieve specific objectives.

An institution or an individual invests in basic research within a particular context, in a setting in which the research investment is aimed at the creation of valuable results. In a university, research makes a contribution to the education of students, and to fields of knowledge, which may impact the economy, the environment, the health of the populace, or the security of the nation. Government laboratories exist in the context of a particular government mission, be it health care, energy, defense, agriculture, etc., which affects the value context of that institution's basic research efforts. The same is also true in industry research, where the objectives and applications are clear.

Management of all research, including basic research, is aimed at maximizing the value that is likely to be created from the research investments, where the notion of value is particular to the mission and setting of the institution. Implementing this principle forces the institution and the individuals within the institution, to develop a clear understanding of what value is, and what can be done to increase it. Choices of research areas, for both basic and applied research, reflect this understanding of value. Realistic measures of progress and of success are developed in the value context, and employed to influence the course of research. In short, a set of processes, deeply involving the researchers themselves, but including the other stakeholders is created, affecting basic research at many stages—in the allocation of funding across sectors, the decisions on resources for particular efforts, and the measures of progress and results.

opment research are all vitally important for economic progress. However, basic research is the foundation of most technological change, as explained below.

Although the critical role of basic research in the development of new technology is sometimes easily observed, as in the case of biomedical research undertaken explicitly for the purpose of developing new drugs, more often the relationship between fundamental science and new or improved goods and services is quite complex and indirect. Only retrospective examination of specific cases makes evident that basic research has been the foundation of many revolutionary technological innovations. The following are some examples:

- **Lasers** owe their heritage to basic research by a number of scientists including: Albert Einstein, the first to recognize in 1917 the theory of "stimulated emissions;" Charles Townes of Columbia University who in 1958 discovered how to create a focused microwave beam; Townes and Arthur Schawlow (of Bell Labs) who published the theory of how stimulated emissions would work with shorter wavelengths, including those in the spectrum of visible light; and Theodore Maiman who constructed the first laser at Bell Labs in 1960. Today, laser applications have a wide variety of applications, including surgery, telecommunications (lasers with fiber optics), printers, precision drills, and other machine tools.

- **X-rays** were initially and fortuitously discovered in 1895 by William Roentgen, as he was experimenting with cathode rays. Since then, many scientists and engineers have developed diverse uses for x-rays. The best known applications are in the medical field. In more recent years, the value of x-rays has been enhanced greatly by the mathematical contributions of physicist A.M. Cormack (for which he won a Nobel prize). Cormack's work contributed to the development of computerized axial tomography (CAT), which has revolutionized medical imaging and diagnosis. Today, CAT scans produce three dimensional x-ray images. X-rays are also used for the detection of internal stress defects in materials and in the assembly of small electronic microcircuits. X-rays also have security applications, such as in airport baggage inspection.

- **Semiconductors** were first discovered in 1886 by German chemist Clemens Winkler, but remained little more than a laboratory oddity for many years. Before World War II some uses were found for semiconductors (in radars, for example), but wide-ranging use waited until the advent of transistors in 1948. Semiconductors have since created a revolution in electronics. Tiny electric circuits are now used in every imaginable electric device—miniature radios, television, telephones, airborne navigational aids, diagnostic instruments, etc. Transistors were developed at Bell Labs by American physicists Walter Brattain, John Bardeen, and William Shockley. Just as the transistor replaced the vacuum tube, integrated circuits and microprocessors replaced transistors.
- **The Global Positioning System (GPS)** owes its origin to theoretical research on atomic structure and to the construction of an atomic clock. Work on an atomic clock, which began before World War II, was initially undertaken by researchers interested in the effects of gravity on time. These researchers certainly did not anticipate the contribution of their work to a GPS constellation of 24 satellites that make it possible to provide extremely accurate information on location. GPS has had a major impact on transportation and its economic impact is anticipated to grow very rapidly (e.g., in the "smart" highway program).
- **Treatment for HIV disease and AIDS**—especially the impact on HIV protease inhibitors on slowing disease progression and prolonging survival—resulted from more than 10 years of public and private sector funding of biomedical research in several areas including immunology, virology, and biochemistry (see Merck discussion in Case Studies section). Research at the NIH elucidated the pathogenesis of HIV infection and the slow but steady deterioration of the immune system by HIV that eventually leads to AIDS, and helped characterize the molecular composition of HIV. Research conducted by academic and other nonprofit laboratories demonstrated the capacity of HIV to replicate and seed numerous reservoirs of virus throughout the immune, central nervous, and gastrointestinal systems. Research conducted by several pharmaceutical companies contributed fundamental knowledge about the role of HIV protease enzyme in the HIV life cycle—including its molecular 3-D structure and the mechanism of the emergence of viral resistance—and eventually led to the design of several potent HIV protease inhibitors that prevent replication of the virus and reduce viral levels in the body.
- **Xerography,** invented by Chester Carlson in 1938, had a profound impact on information processing (see Xerox discussion in Case Studies section), but that impact was delayed by a quarter of a century. Many advances in technology, basic science, and engineering were necessary before Carlson's discovery was commercialized. Research in the private labs of Battelle Memorial Institute provided the foundation for Haloid-Xerox (now Xerox Corporation) copier products, more than 20 years after the original discovery by Carlson. Xerox acquired a license to the process in 1947 and assembled a large team of scientists and engineers to further advance the xerographic process, filling in the gaps in fundamental knowledge that stood in the way of necessary product improvements. Xerox sponsored both basic and applied research and involved scientists and engineers in many disciplines, generating advances that led to the modern high-speed copier.
- **The Internet**. When BBN and others built the ARPANET—the forerunner to the Internet—in 1969, its primary goal was to enable scientists and engineers across the country to share ideas and information. But its efforts also brought together more than a century of fundamental research and discovery. The size, speed, reliability, and cost-efficiency of network switching equipment were initially

based on advances in miniaturization of electronics—particularly digital electronics—which had its origins in the development of logic circuits in the 1850's. Early circuits were built with various complex forms of electrically controlled switches, such as the Strowger step-by-step switch, which was the heart of the first completely automated telephone exchange. The invention of the transistor made possible economical and reliable packet switching, which depends on a robust mesh of large numbers of relatively inexpensive, dedicated computers able to run unattended for long periods. The links between these switching elements also rest on the results of basic research in information theory. In the 1940's, Claude Shannon, a scientist at Bell Labs, presented a means of symbolically analyzing the behavior of switching circuitry. Shannon's work was closely related to the system of symbolic logic developed by George Boole in 1848, and which has come to be known as Boolean algebra. Today's scientists and engineers still rely on these developments as they continue to enhance the Internet with remarkable speed.

Hundreds of additional cases could be cited to illustrate that the economic and social effects of basic research are pervasive in our society.

The innovations described above and many others demonstrate certain characteristics of technological advances:

1. The benefits of basic research are large, widely dispersed, and frequently unanticipated;
2. New scientific discoveries and technological advances generally have a rich history of basic science behind them, often building on and extending the work of others;
3. Technological advances often combine discoveries in several fields—see the above example where x-rays, mathematics, and computer technology were combined to develop CAT scans;[1]
4. Knowledge resulting from basic research tends to be widely dispersed and employed by researchers in other fields;[2]
5. Even applied and development research can help drive new basic discoveries:
   - by developing new tools and instrumentation for use in basic research;
   - applied researchers frequently must step back and perform basic research to fill gaps in fundamental knowledge that are required to achieve their practical goals;
   - development researchers often make new discoveries in the course of their applied work that adds to our basic understanding of nature.

For further observations on the discovery and innovation process see Box 1, page 7.

THE ECONOMIC IMPACT OF BASIC RESEARCH

There is strong evidence indicating that basic research in science and engineering has made a major contribution to the growth of the U.S. economy. The study of individual cases shows that discoveries and innovations derived from basic research have led to new products and industries that employ thousands of workers nationwide. Of course, technological change resulting from basic research often results in temporary displacement of workers in older industries, as well. And basic research is only one of several factors—such as the education of the labor force and the stock of capital—that accounts for economic growth. Thus, identifying the net impact of research expenditures on national economic growth generally involves the employment of sophisticated models of economic growth, an area of economic research that has been ongoing over the last four decades.[3] A conservative interpretation of the results of this work indicates that total R&D accounted for 12 to 25 percent of the annual growth in productivity during post-World War II decades.[4] This suggests that the cumulative impact on living standards has been very large. Moreover, a new view of economic growth suggests that R&D has dramatically larger economic effects.[5]

Basic research is a critical part of this contribution to growth. One reason that basic research is so important is that advances in fundamental knowledge tend to be widely dispersed, with discoveries extended by other scientists, and built on in ways that often result in enormous economic benefits for society over a prolonged period. Also, as noted earlier, advances in applied and development research activities are often critically dependent on earlier advances in fundamental science and engineering derived from basic research.

The Rate of Return on Basic Research Investments

Another approach for gauging the impact on productivity of basic research, and of R&D generally, is to estimate the internal rate of return on R&D investments made by individual firms or industries.[6] Many such studies provide strong evidence of the economic benefits of R&D.[7] Rate of return studies measure both the increase in productivity experienced by the industries funding R&D and the "spillover" benefits that improve productivity in other industries. Although the range of estimated rates of return is quite wide, the consensus is that on average private returns are very high relative to other investment opportunities—on the order of 20 to 30 percent annually, or roughly double the average historical return to stock market investments. Moreover, "social" returns on R&D investments—that is, the returns to society as a whole—are substantially higher than private returns.[8] The social returns to basic research are often particularly high due, in part, to the wide dispersion of fundamental knowledge, which frequently leads to additional discoveries and applications in diverse fields.

The difference between private and social returns on investments in basic research, often described as a "market failure," is an important justification for public funding of research and for tax policies to encourage increased research (see Box 2, page 12). Business investments in research are driven by expected private benefits. In order to maximize the benefits to society as a whole, the optimal government investment strategy is to provide additional funding for those research activities that offer social returns in excess of private returns.

Although basic research investments are commonly viewed as "high risk," this best describes the private sector's, rather than the public sector's, investments in basic research. A private firm must capture some minimum level of benefit over a reasonable period of time to justify its investment. Because the results of basic research are often unpredictable (in outcome and in timing) and widely dispersed, capturing adequate returns at the firm level is difficult, and consequently risky. But for government, the returns to public investments in basic research need not be captured by an individual entity—be it a researcher, university, or agency—in order to justify the investment. Rather, so long as the results are widely dispersed and used by many different individuals and institutions, the public benefits from the government's investments. The risk, then, is much smaller for these public investments than it would be for a comparable investment by a private firm.

Further, the "portfolio" of basic research investments which the government holds is far larger and more diversified than that of any individual firm. As a result, risk associated with the whole universe of government-funded projects, which will include many winners and losers, is much lower than would ever be possible within a single firm.

Regional Economic Benefits

Basic research performed in major research universities (and in other public and private labs) often has a large indirect impact on the economy of the regions where the universities are located. For example, a study by BankBoston shows that research conducted at MIT has had a large impact on the economy of Greater Boston, where numerous knowledge-based companies are located.[9] There are now estimated to be more than one thousand MIT-related companies located in Massachusetts with world-wide sales of $53 billion. About 125,000 workers are employed by these companies in Massachusetts. World-wide employment of these MIT-related companies is about 353,000 workers. Of course, many other regions of the nation, such as the Silicon Valley of California and the Research Triangle of North

BOX 2

WHY DOES GOVERNMENT SUPPORT BASIC RESEARCH?

The federal government is by far the most important funder of basic research (see Appendix 1 for an overview of government and industry resources for basic research). What accounts for this role? There are two general explanations, one defined by the needs of the government itself, and the other by the inability of private markets to adequately respond to the needs of the economy and society at large. First, government funds basic research, and R&D in general, simply as a matter of procurement. Just as government purchases pens and pencils to carry out administrative tasks, it also "purchases" research to support agency missions. In this sense, the Department of Defense funds research in physics and computer science in order to generate knowledge that will lead to better defense systems. In general, this explanation applies more strongly to development activities than it does to basic research, which explains the predominance of federal development spending over basic research spending. That is, short-term, well-defined needs take precedence over longer-term, less-defined needs.

But there is a second, broader category of explanations for why government is the primary funder of basic research. These explanations transcend the narrowly-defined needs of the various federal agencies. As we discuss throughout this chapter, basic research has resulted in countless social and economic benefits in the United States. The very fact that the benefits of basic research are so broadly realized explains the central government role in its support.

In economic terms, the knowledge that results from basic research is, by and large, a *public good*. Unlike private goods, a public good can be used simultaneously by any number of individuals without anyone's use diminishing its supply. For example, one person's use of a scientific formula does not exclude another person's use, nor does it diminish the formula in any way. This general characteristic has many implications, one of the most important of which is that it makes private ownership of a public good difficult and economically inefficient.

Because an individual or firm cannot easily reap all of the benefits of the scientific formula (or other potential outcomes from basic research), these private market actors tend to underinvest in basic research activities *from society's perspective*. As a result, a gap emerges between the prevailing level of private investment in basic research and the level that would maximize the benefits to society at large. Economists identify this gap as a *market failure* and point to government intervention as necessary to fill this funding gap and exploit the positive *externalities* of basic research.

The Pfizer case study (see Case Study section) puts the distinctions of public and private support for R&D in very practical terms as they apply to drug innovation: "Industry and academia each play vital yet different roles in [the innovation] process, with industry focusing on integrating basic science findings in a directed, applied process of managed drug development...This development enterprise is considerably different from the inquisitive, open-ended nature of basic academic research."

Carolina, have benefited similarly from the presence of major research universities.

PUBLICLY-FUNDED BASIC RESEARCH IS CRITICAL TO PRIVATE SECTOR INNOVATION

As described in Chapter 3, universities are the largest venue for basic research, but it is also performed in government laboratories, industry laboratories, and in other private nonprofit institutions. In several of the historical cases mentioned earlier in this chapter, the basic research underlying technical advances was undertaken in private labs operated by business firms. Nevertheless, empirical evidence on industrial innovation in earlier decades found that many important new products and processes in the marketplace could not have occurred without academic research.[10] Today industry continues to perform basic research in many areas (see Appendix 1 for an overview of industry support for basic research), but heightened competitive and financial pressures have encouraged many firms to place more emphasis on short-term applied and development work (see Chapter 3). Consequently, government-funded (primarily university-based) basic research is now more critical to industrial technology.

The growing importance of publicly funded research in industrial innovation was recently confirmed in a 1997 study based upon an analysis of citations in patents issued to U.S. industry.[11] U.S. patent law requires that the front pages of patents report "other references," i.e., important prior art upon which the patent improves. The study examined 430,226 citations on the front pages of 397,660 patents issued from 1987 to 1988 and 1993 to 1994. *This analysis revealed that 73 percent of the research papers cited by industry patents referred to "public science"—government funded research reported in papers authored by scientists working in academic, governmental, or other institutions.* Only 27 percent of cited materials was authored by industrial scientists. Moreover, a comparison of citations in the two time periods showed rapid growth in the dependence of private technology on public science.

Although much of the research undertaken in universities is intended to advance fundamental knowledge in science and engineering, it frequently has very practical applications. Indeed, in recent years many talented scientists employed by research universities have participated in cooperative research efforts with businesses and consequently, a growing proportion of their research has become directed at commercially valuable objectives. Moreover, the major research universities have very active technology transfer offices working to assist businesses to acquire new technology. As noted in Chapter 3, while research universities perform large portions of the basic research underlying commercial technology, they also benefit society by training future scientists and engineers. In fact, the training of future researchers is the most important thing that universities can do to ensure a strong *future* for basic research.

Because of the characteristics of basic research, government is its primary funder (see Box 2, page 12). CED strongly disagrees with the "new thinking" currently in vogue among some commentators[12] which holds that government funding of basic research is unnecessary in a free market economy and that a reduction in funding for basic research would have little economic effect because business innovation relies primarily on existing technology. The evidence on patent references described above indicates that this "new thinking" is seriously flawed. Technological development in industry is highly dependent on publicly funded basic research undertaken in universities and elsewhere.

THE FUTURE IMPACT OF BASIC RESEARCH

Basic research has been tremendously important to our economy and society throughout this century. But what of the next century? Does basic research promise to bring just as big a payoff to as many areas of our lives in the future? The answer, we believe, is a resounding yes. The challenges and opportunities facing our economy and society in the years to come are varied and plentiful. And in case after case, advances in fundamental scientific knowledge are necessary before we can hope to see remedies or benefits.

For example, as computers and information technologies become increasingly sophisticated, our expectations for future progress will be unrealized absent advances in fundamental knowledge. The hopes for a "computer that learns" require significant scientific breakthroughs—possibly in DNA research as well as in computing[13]—and not simply steady technological improvements and tinkering.

DNA research itself holds great promise for benefits in all aspects of human health and well-being. But moving from the current process of mapping genes to that of understanding the maps themselves and the significance of gene sequences is an enormous challenge that will occupy scientists for decades.

Basic research will also be important in identifying and defining social problems that vex us today. For example, the current debate swirling around global warming is a measure of our ignorance in this area. With scientific progress we can move beyond political contention to properly defining problems and determining remedies, which themselves will likely be derived from basic research.

Of course, the prospects for future scientific breakthroughs in specific areas are largely unknowable to us today, and in many cases, appear almost unfathomable. Ideas that currently exist in theory would, if brought to fruition, redefine the way we exist as human beings and as a society. "Nanotechnology" is but one remarkable example. The ability to manipulate molecules systematically, today a theoretical proposition, may offer the potential to live in a world of science fiction, where nature can be replicated in a million different ways to any number of ends. Basic research itself might ultimately prove molecular engineering to be fantasy rather than reality; but speculating about its potential underscores the dramatic nature of scientific progress and the tremendous unknowns that are associated with it.

The list of potential outcomes in basic research is endless, but in considering the opportunities and challenges of the future, one way to think of basic research is as low-cost insurance—currently, basic research uses less than one-half of one percent of GDP to create very significant long-term economic and social gains.[14] We have only the slightest understanding of what lies ahead. But our greatest hope for capitalizing on unknown opportunities and avoiding unknown calamities is investing in the scientific knowledge that will meet these unknowns in the decades ahead.

Chapter 3

THE EVOLVING AMERICAN BASIC RESEARCH SYSTEM

The success of basic research in this country is due in large part to the unique characteristics of the American research system. The American way of doing research is characterized by the flexibility and heterogeneity of its institutions and disciplines, the intense competition for research funds, and the independence and creativity of individual scientists and engineers. More than anything else, the high caliber of our individual scientists and engineers accounts for the exceptional quality of our basic research. In the words of one observer, American scientists are a "national treasure chest." Moreover, the economic impact of our basic research also reflects the responsiveness of the U.S. economy to technological change, innovation, and commercial needs.

The dynamic character of the U.S. basic research system is particularly evident now as the entire R&D system is undergoing substantial change. The characteristics of this most recent wave of changes include the following:

- *Because of increased competitive pressures, many businesses are taking steps to improve the management of their research activities and the return on R&D investments.* This is reflected in (1) greater emphasis on applied and development activities, which have more timely and certain payoffs, (2) efforts to become more competitive by reducing time-to-market; and (3) actions to reduce R&D costs, including the downsizing of large industrial labs.
- *The priorities of the federal government are changing*. (1) The end of the Cold War, which resulted in sharp cuts in defense appropriations, has placed basic research in areas traditionally funded by the Pentagon at a disadvantage, while funding for certain civilian priorities, particularly health research, continues to grow rapidly. (2) Unless entitlement programs for the elderly are reformed, entitlement spending will crowd out other discretionary expenditures, creating the potential for declines in federal investment in basic research. (3) With heightened concern for our international competitiveness, the federal government has increased funding of collaborative efforts by government and business to accelerate commercial technology, a change that threatens to squeeze resources for future basic research.
- *Modern technology is bringing forth radical changes in the research enterprise itself.* The revolution in information technology has resulted in more rapid transfer of knowledge and increased opportunities for one researcher to build upon the discoveries of others. This trend is particularly important in those fields of research where modern technology permits rapid replication of work that the original researcher took years to complete.
- *In many cases university research has taken on a greater entrepreneurial character.* Federal legislation enacted in the 1980s to facilitate economic development now permits universities to hold patents to, and license, work funded by the federal government, and business has increased funding of research in universities.

This trend is also explained by the ability of industry, particularly the biotechnology industry, to translate basic research into commercial products very quickly.

- *Collaborative efforts between basic research institutions—universities and business, business and government etc.—and between disciplines are growing in importance.* Rapidly rising research costs, particularly for capital equipment, have been an important motivation for institutional collaboration. Inter-disciplinary collaboration has been driven by the nature and complexity of the questions explored. International collaboration in research has also expanded, encouraged by the need to share costs, especially in projects with large capital infrastructure requirements such as high energy physics and space exploration.
- *Increased foreign presence in R&D has intensified in recent years, even in basic research.* Other countries are increasing their investments in R&D and basic research, including developing countries which spent virtually nothing on R&D just a few decades ago. This trend is reinforced by the rapid dispersion of knowledge and the tendency of international corporations to locate research in countries where skilled workers are abundant and specialized skills are available. The increased availability of opportunities for employment abroad has also reduced the number of foreign scientists—including those educated in the United States—choosing to locate in the United States.

This chapter briefly describes the qualities of the American basic research system that have led to its success, as well as the evolving nature of these qualities: its institutional structure, the human infrastructure, and the system of funding. Finally, the chapter points to international trends that promise an increasingly global context for American basic research in the years to come.

TODAY'S BASIC RESEARCH INSTITUTIONS

The current institutional structure for basic research is largely a legacy of important decisions made by government and industry after World War II and throughout the Cold War about how and where to allocate resources for basic research (see Box 3, page 17). One key characteristic of the American basic research enterprise since the late 1930's has been the predominance of federal government funding relative to other funding sources (see Box 2, page 12). Industrial and other sources of funding, though smaller, have also played important roles in supporting basic research (see Appendix 1 for an overview of funding patterns for basic research).[15]

Yet, financial resources alone do not account for the high quality of basic research in the United States. How, or to whom, those resources are allocated matters a great deal. Perhaps more than any other country, the United States relies on competitive mechanisms in allocating funds for basic research. Competitive, peer-reviewed grants to individual investigators are a hallmark of the American system. The basic research institutions that have succeeded in this allocation mechanism, primarily large research universities, have set the standard for quality in the post-Cold War era. On the other hand, research institutions that have grown up under a different regime, one defined by centralization and top-down management, have struggled to justify their cost-effectiveness in an era of tight budgets.

Industry

Basic Research Conducted by Industry

Industry is, by far, the largest funder of total R&D in the United States, but its relative presence in *basic research* is less significant (see Appendix Figure 2 in Appendix 1). Basic research conducted by industry is largely targeted at its own proprietary product development—often filling in the gaps remaining from publicly-supported research and in areas of inquiry that are necessary to proceed with product development[16]—though a small amount of industrial basic research is conducted for the government, particularly in the area of defense.

Industry spending on basic research varies greatly from sector to sector. A relative few, such as pharmaceuticals, are highly dependent on their

BOX 3

THE HISTORICAL EVOLUTION OF TODAY'S BASIC RESEARCH SYSTEM

The basic research system that exists in the United States today—with world-class research funded and conducted by federal agencies, large corporations, state governments, public and private universities, small businesses, and private nonprofit research institutions—has come a long way from its infancy a century ago. At the turn of the century, scientific inquiry was still largely a European affair. At the time, the United States was known for its individual inventors, the clever non-scientists tinkering in their homes to discover a new product or process, but rarely a fundamental scientific insight.

With the emergence of large, multi-product corporations and the scientific and technological demands of World War I, the modern American basic research enterprise began to take shape. In a drive to innovate, large firms turned to scientists and engineers for expertise (most significantly in chemicals, petroleum, and electrical machinery), establishing in-house research laboratories or contracting out to independent labs. During these years, federally-sponsored research was largely agricultural, though the land grant universities did sponsor other important areas of research, often related to local and regional economic needs.

World War II was a watershed for American research, creating a public enthusiasm for science and technology that would carry over into the post-war years. The aftermath of World War II created an infusion of resources into basic research directed to military objectives, codifying a system of public funding that flourished during the post-war period as it was enlarged to address civilian objectives as well. Under this system, basic research projects were funded by the government and conducted in universities, government laboratories, and private companies.

Vannevar Bush's post-war blueprint[17] for public research led to the creation of the National Science Foundation (NSF) and with it, a system of allocating federal dollars for all of the sciences based on scientific merit. Most of the federal resources devoted to research were (and are) allocated through federal agency missions. The federal government invested heavily in research as a means to achieve supremacy in weapons systems and space technology. Government investment in health research also grew rapidly during this period, as public policies sought to focus the nation's scientific expertise on major diseases. Clearly, during these years, government funding for basic research was largely targeted, even if broadly so.

Whether funded by the NSF or by other federal agencies, publicly-supported basic research came to be characterized as "individual investigator" research. For it was the individual investigator who would "define problems and design the best approaches to solving them."[18] In the case of NSF grants, this process was predominantly investigator-initiated. But even within the narrower confines of agency missions, basic research was largely driven by the expertise of scientists, rather than through "task oriented management by sponsors or ultimate users."[19]

As the system for publicly-supported basic research took shape, many large U.S. firms expanded their own basic research activities. The Cold War era also marked an extraordinary economic period during which many firms were able to command significant market power. Companies like AT&T, Xerox, General Electric, and Eastman Kodak used the resources from this market power to fund activities in some of the nation's premier basic research laboratories. Indeed, work at industrial labs would lead to numerous Nobel prizes for scientific breakthroughs.

The end of the Cold War marked a turning point for basic research in the United States. By the 1990's, the federal labs, which sustained a great deal of basic research after W.W.II, faced an uncertain future. Universities also prepared for belt-tightening in response to an expected decline in federal support. As businesses faced an increasingly competitive and global marketplace, they began to shift their R&D activities toward projects with short-term horizons.

long-term basic research investments for new products and processes, while others spend very little, if anything, on basic research. In the aggregate, industry places a much greater emphasis on shorter-term development activities in the allocation of its R&D dollars, leaving the majority of the nation's basic research investments to the public sector.

But there is much more to the differences between industrial basic research and basic research supported by the government (performed primarily in universities) than the relative size of the investments. Basic research in companies and basic research in universities may both achieve new, fundamental scientific understanding, but they are characterized by different motivations and different goals. The university researcher is attempting to ask and answer questions of deep scientific importance, to generate knowledge and theories with the most power to explain natural processes. The industry researcher has a very targeted goal: to gain understanding that is essential for further development of technology, which in turn, is expected to drive development of new products. When university researchers make an important basic discovery, they and their colleagues immediately increase their efforts along similar lines to confirm and amplify the discovery. Further, the academic researchers will direct new efforts toward questions that are inherently most interesting. Once the company researcher has made a discovery, he or she attacks the next set of problems that must be solved for product development to continue, and may leave elaboration of the discovery to others (including university researchers).

Industry as Partner and Collaborator in Basic Research

While industry performs a significant share of the nation's basic research, increasingly companies have also found it useful to support basic research projects at universities, and to collaborate with the individual investigators. Direct industry funding of "sponsored research" at universities, though small relative to government funding, has expanded significantly, from 4 percent of total support for academic research in 1980 to 7 percent in 1996 (see Appendix Figures 8 and 9 in Appendix 1). Much of this expansion occurred in the biomedical field where companies have rapidly translated basic research discoveries into new product development programs in therapeutics, diagnostics and medical devices.

The willingness of industry to fund sponsored research has been spurred, in part, by the Bayh-Dole Act of 1980, a federal law which allows recipients of federal grants to retain title to inventions made in the course of research funded by the grant.[20] In practice, this means that an industrial sponsor may have the right to license proprietary rights not only to the work which is being sponsored, but also additional rights to earlier inventions funded by government grants. Thus, the industry sponsor may be able to license a coherent "package" of intellectual property. In certain cases these rights may provide a sufficient platform for the company to initiate its own internal R&D toward the development of new products.[21]

At the major research universities in the United States, a sponsored research contract negotiated between a company and the university's technology transfer office has the following attributes: the company provides a specific amount of funds in return for the investigator's agreement to perform an agreed-upon research plan; the company receives an option to license any new inventions, which takes the form of a first right of negotiation; the company agrees during the option period to fund any related patent applications filed by the university; and the company is given a brief period in which to review for patentability any written or oral presentations (such as conference presentations or journal articles) prior to their public disclosure. The latter understanding maintains the university's right and need to freely disseminate its research findings, while preserving both the sponsor's and the university's interest in the value of any proprietary inventions.

With appropriate safeguards for the role of the university,[22] industry sponsorship of basic research can bring benefits to both parties. The industry sponsor gains access to some of the most creative minds in its field of interest, which can stimulate important breakthroughs. The company is also able to license technological innovations and associated patent rights that can be the basis for important new product lines. Indeed, the biotechnology industry originated with the formation of new companies around technologies that had been licensed from universities.

The university benefits by allowing its faculty members to supplement publicly-funded grants with additional support. For many researchers this additional support contributes to maintaining the productivity of their laboratories. In addition, if a company converts technology licensed from the university into a successful product or service, the university receives milestone payments and royalties, which in the case of a blockbuster product (such as a major pharmaceutical) can amount to millions of dollars per year. An additional intangible benefit of a well-managed collaboration can be the value of the intellectual collaboration between the individual researchers in the industry and university laboratories.

Industry Benefits from Open Dissemination of University Research

The increasing significance of industry-university research partnerships does not diminish what continues to be the primary channel of benefit of university basic research to industry and the economy at large: the open dissemination of new knowledge, without restriction on use or on the number of users. The primary benefit of university research to society stems from the free and open dissemination of new knowledge, whether the research is funded by the government, foundations, or corporations, and whether or not the research leads to patentable inventions. Indeed, most technology transfer agreements at major universities are designed to permit only a brief delay in public dissemination of industry-sponsored research for this reason.

As discussed in the previous chapter, recent analyses of patent data suggest that the disseminated results of university research has accounted for a great deal of the new knowledge embodied in commercial patent applications. There is also evidence that open dissemination of university research—through publications, public meetings and conferences, and through informal channels—has been much more important to industrial innovation than more restrictive relationships.[23]

Open dissemination of basic research does not occur solely in universities. The case of AIDS research at Merck (see Case Studies section) illustrates how and why many private companies also subscribe to a standard of open dissemination of knowledge derived from many of their basic research activities. As the Merck case demonstrates, even when there are no legal barriers to establishing proprietary rights over research findings, companies like Merck have found that a more open approach to dissemination not only yields greater benefits to society at large, but in many cases to themselves. Also, industry researchers are, like university colleagues, motivated by prestige to disseminate their work openly through peer-reviewed journals whenever possible. The prestige generated by publication benefits the company by enhancing its recruitment of top-notch scientists and increasing the perceived value of the company's research, and ultimately its products.

Universities

Without question, the most important institution in American basic research is the research university. The research university system has become the nation's largest basic research enterprise as a result of large and sustained federal funding throughout the post-World War II period (see Appendix 1 for an overview of resources for university research). But the real success of the system is based upon:

1. the unique structure that supports the individual university researcher, rather than the institution itself;
2. the dual role that universities play in conducting research and training graduate students;
3. the competitive funding mechanisms for university research;
4. and the flexibility and diversity of research universities.

As we describe later in this chapter and in the previous section, the success of the university research system has contributed to a great deal of business interest in recent years, leading to new roles and challenges for universities and their researchers in the marketplace.

University Support for the Individual Investigator

The heart of the university research enterprise is the highly-skilled independent investigator (see "The Critical Value of the Individual Researcher," page 27, for further discussion). Typically tenured or tenure-track faculty members,[24] university scientists rely on a combination of university support (in the form of salary, facilities, and research assistants) and external grants to conduct their research. The university research environment allows faculty scientists considerable autonomy to define the nature of their research projects, to pursue external support for the projects, and to carry out the research in a way that is suitable to the researcher and the funding agency (or other entity). The quality of university research in general is guided by a competitive process through which thousands of individual university scientists nationwide seek external (mostly federal) grants. Of course, department chairs, deans, and university administrative officials also play important roles in shaping and ensuring quality in university research portfolios. Particularly important in this regard is the extensive review undertaken in hiring faculty members.

As the trends in federal support for university research (outlined in Appendix 1) illustrate, university scientists often seek support from a number of agencies, because the fundamental nature of their work can support a number of federal missions.[25] (For example, the same grant application may be eligible for consideration by the National Science Foundation, the Department of Defense, and the National Institutes of Health). The plurality of routes to funding has increased grant opportunities for applicants and sustained the flow of new knowledge despite shifting agency priorities and budget fluctuations (see Appendix 1 for a description of these funding patterns). The availability of multiple funding sources has permitted a greater diversity of scientific investigations and approaches than would be possible under a single-source funding structure.

The educational function of universities gives them a particular advantage in basic research. As an integral part of their training in science and engineering, graduate students are employed in university labs as assistants to the faculty researchers. Graduate students at research universities are technically proficient, intimately familiar with cutting-edge research, and highly motivated. Their PhD theses and their future careers as researchers depend on making a significant intellectual contribution by performing research that is worthy of publication in first-tier, peer-reviewed journals. Indeed, the laboratory experiments that lead to fundamental discoveries are typically performed by graduate students and post-doctoral fellows, whose tuition and stipends are funded by government and foundation grants.

The Diversity of Research Universities

Nearly all university research (96 percent) conducted in the United States is concentrated in about 200 public and private institutions.[26] Twenty-five universities (see Figure 1) account for about 35 percent of total research expenditures by the 3,600 higher education institutions in the United States. These top 25 recipients account for 39 percent of federally-funded research. The top 100 account for 78 percent of total federal funding—representing only modest diffusion of resources over four decades of expansion of the university system in the United States.

Even though the diffusion of total resources has not changed dramatically, many more academic research institutions receive federal research funds today than did so 25 years ago—from 567 institutions in 1971 to 875 in 1993.[27] Almost all of this increase has gone to non-doctorate granting universities—i.e., liberal arts, two-year community colleges, and other technical and professional schools.

Given the emphasis in the United States on investigator-initiated grants, it follows that the reputation of a research university and its collective impact as a research institution are the aggregate of the productivity, reputation, and grantsmanship of its individual faculty members and the students they recruit to their laboratories. As individual scientists and engineers move from one university to another, the financial and educational

Figure 1

Top 25 Research Universities, by Total Research Expenditures and Federally Financed Research in 1995

Total Research Expenditures / **Federally Financed Research**

(dollars in thousands)

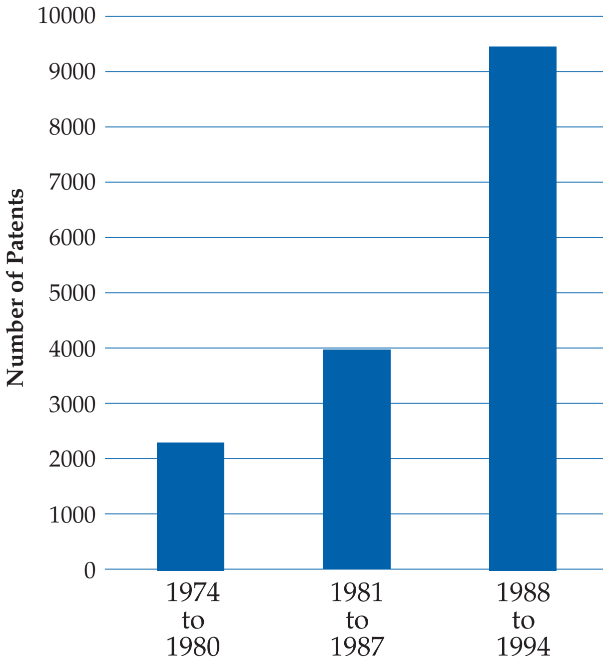
Total Research Expenditures		Federally Financed Research	
Total, all institutions	*$21,654,220*	*Total, all institutions*	*$12,884,158*
1 University of Michigan	$443,070	1 University of Washington	$291,284
2 U WI Madison	$403,541	2 U CA San Diego	$284,445
3 University of Washington	$289,160	3 University of Michigan	$275,956
4 MA Institute of Tech 1/	$370,800	4 MA Institute of Tech 1/	$273,543
5 Texas A&M University	$362,539	5 Stanford University	$273,157
6 U CA San Diego	$357,333	6 Johns Hopkins Univ 2/	$259,049
7 Cornell University 1/	$343,786	7 U WI Madison	$299,381
8 University of Minnesota	$336,524	8 U CA San Francisco	$224,271
9 Johns Hopkins Univ 2/	$331,387	9 Cornell University 1/	$207,391
10 Pennsylvania State U	$330,881	10 Columbia University	$206,495
Total, top 10 institutions	*$3,669,321*	*Total, top 10 institutions*	*$2,524,972*
11 U CA San Francisco	$329,742	11 Harvard University	$203,965
12 Stanford University	$318,871	12 U CA Los Angeles	$201,773
13 U CA Los Angeles	$303,668	13 U of Pennsylvania	$200,895
14 University of Arizona	$292,351	14 University of Minnesota	$194,819
15 U CA Berkeley 1/	$291,200	15 Pennsylvania State U	$187,481
16 Harvard University	$276,422	16 Yale University	$174,868
17 U of Pennsylvania	$272,393	17 University of Colorado	$168,674
18 University of Colorado	$249,695	18 University of Arizona	$168,791
19 Ohio State University	$246,287	19 U of Southern California	$163,606
20 U of Illinois Urbana	$246,174	20 U CA Berkeley 1/	$157,826
21 Columbia University	$244,991	21 U of NC Chapel Hill	$156,626
22 U CA Davis	$244,116	22 Duke University	$148,526
23 Yale University	$231,819	23 Washington University	$146,921
24 U TX Austin	$228,676	24 University of Pittsburgh	$144,457
25 U of Southern California	&222,159	25 U TX Austin	$143,939
Total, top 25 institutions	*$7,667,885*	*Total, top 25 institutions*	*$5,089,169*

1/ These data do not include research expenditures at university-associated federally-funded R&D centers.
2/ Johns Hopkins University data do not include Applied Physics Lab, with $447 million in total R&D expenditures.
NOTE: Because of rounding, data may not add to totals.
SOURCE: National Science Foundation, Science Resource Studies Division, Survey of Scientific and Engineering Expenditures at Universities and Colleges, FY 1995 (data available at www.nsf.gov).

benefits of their research activities move with them. Consequently, while there are differences in quality and in economies of scale among institutions which tend to sustain institutional patterns of research funding over time, the hierarchy of research universities that receive the most federal research support is not static. Competition for research grants by individual investigators has a similar competitive effect on the academic institutions that employ them. It is in universities' interest as producers and disseminators of knowledge to employ the highest quality scientists.[28]

Figure 2

Number of U.S. Patents Awarded to Academic Institutions



SOURCE: National Science Board, *Science & Engineering Indicators—1996* (Washington, DC: U.S. Government Printing Office, 1996), Appendix Table 5-42.

Research Universities and the Marketplace

Two important trends are helping to shape the face of tomorrow's research university. Both promise to push university research closer to the marketplace. The first is the ability of universities and academic researchers to reap financial rewards for inventions that are to be commercialized by industry. The other related trend is the growing number of industry-university collaborations and the increasing emphasis of research institutions on developing such collaborations into a major long-term source of funding.

For nearly 20 years it has been the policy of the federal government to encourage universities (and other performers of government-supported research) to file patents and to transfer useful inventions to industry for commercial development. As described earlier, the key legislation related to this policy was the Bayh-Dole Act of 1980, which ushered in a new era for university research. Figures 2 and 3 illustrate the magnitude of these changes. A gauge of the impact of Bayh-Dole is the number of patents issued to academic institutions, which increased from 249 in 1974 to 1,761 in 1994.[29]

It is important to recognize, however, that involvement of universities in commercialization of technology is still a small portion of total university research, and, indeed of total industry R&D. For example, the patents awarded by the U.S. Patent Office to universities in 1994 amounted to less than one percent of all patents issued that year. Despite the growing presence of industry in funding sponsored research on campuses, companies provide only seven percent of total university research support.

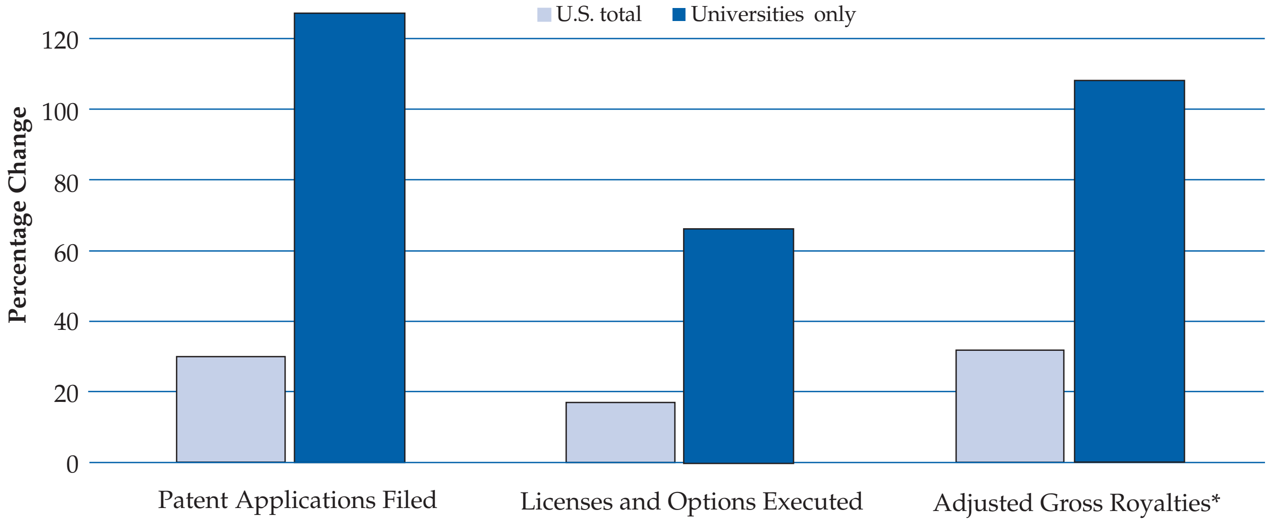
The open nature of university research has always allowed for external funding from many sources, not just the federal government. Nonetheless, the nature of industry funding and the effects of university licensing raises issues and concerns not encountered with public funding. These concerns include the potential for:

- restrictions on open dissemination of research;
- a reorientation of university research to accommodate the interests and needs of industrial sponsors;
- conflicts of interest between the individual financial interests of researchers and the broader interests of the academic department, university, and society as a whole;
- application of criteria other than basic research productivity and teaching performance, such as ability to obtain industry support and generate royalties, in consideration of hiring and promotion decisions for faculty.

Most research universities have developed policies and guidelines that confront these issues, and have promulgated them among faculty, staff and graduate students (see Appendix 2 for two examples of university patent policies). Nonetheless, universities deeply involved in sponsored research must now serve a new constituency, their industrial partners. The acade-

Figure 3

Growth in U.S. University Licensing Activities Relative to U.S. Totals, 1991-95 Cumulative % Change



*Adjusted gross royalties are gross royalties minus royalties paid to other institutions.
SOURCE: Association of University Technology Managers, *Licensing Survey FY 1991-95*, (ATUM, 1997).

mics must cope with a new bureaucracy—the university's Office of Technology Transfer. And the university's administrators must wrestle with a range of potential conflicts of interest on the part of faculty and staff.

Patenting and Licensing of University Research

Because university inventions are frequently made with the use of public funds, universities have a special responsibility to maximize the societal benefit from the use of such inventions. This responsibility goes beyond the need to freely disseminate the descriptions of the inventions, and extends to the manner in which such inventions are commercialized, since patents, by their nature, imply a restriction on use.

Clearly, there is no simple formula by which such decisions can be made. Many leading research universities have technology transfer policies that specifically identify the public interest as the primary criterion for making technology licensing decisions (see Appendix 2). In general, once a university has filed for patent protection on a discovery, it then must decide whether to commercialize the technology on an *exclusive* or *non-exclusive* basis.

Research advances that can be translated into distinct products or services, such as a new therapeutic compound, a new polymer, a new electronic instrument, or a new medical device, are typically considered appropriate candidates for exclusive licensing. In these cases, the protections of both patent protection *and* an exclusive license are essential incentives for a company to invest time, money, and resources in creating a new product. Society benefits from the willingness of industry to make those commitments and bring a useful new product to market.

On the other hand, new knowledge that serves as a research tool potentially benefiting the development of a range of new products in multiple companies, is typically commercialized through a *non-exclusive* license made widely available on commercially reasonable terms. The most prominent example is the Cohen-Boyer patents, assigned to Stanford University and the University of California, which cover the fundamental techniques of gene splicing. Since these patents were issued, Stanford and the University of California at San Francisco (UCSF) have made a non-exclusive license available to all companies involved in genetic engineering for a minimal annual fee starting at $10,000 and a small royalty on sales. These modest requirements have imposed no undue burdens on industry, and in 1997 generated $38.5 million for the two universities.[30] Moreover, basic research institutions have been able to practice the methods without charge.

The distinction between products and tools is needed, since a particularly important tool based on a major breakthrough such as gene splicing may be essential for the unfettered pursuit of additional basic and applied discoveries. If excessive barriers are placed in front of others' entry into a field, important new avenues of research will be impeded. The policies of Stanford and UCSF toward the commercialization of the invention by Professors Cohen and Boyer have become a model for other universities that own a broadly useful tool or process: license non-exclusively; make the terms reasonable; and allow basic researchers to use the technology at no cost. This approach optimizes the benefit both to society and to the university.

The Impact of Industry Funding on University Research

Initial evidence on the growing university-industry research relationship suggests there may be some cause for concern. According to a number of recent studies on the impact of industry support for academic research, industry funding is associated with greater restrictiveness in disclosure of research results and with research that is less basic in nature.[31] This is not to say that industry sways the direction of university research toward applied and development work. Rather, companies seek types of university research projects that suit their needs, and these types of research typically may not be as clearly basic in nature as those supported through federal grants. In the aggregate, there is no strong evidence that university research has shifted away from basic science and engineering, even as industry support has increased substantially.

Yet, given the characteristics of industry funding just described (greater restrictiveness and projects that are less basic in nature), *it clearly is misguided to view industry and government funding for university research as interchangeable*. A significant change in the balance between government and industry funding for university research as a whole would likely impact the character of university research and its dissemination.

Among the conflicts of interest receiving the most intense scrutiny are those that may be generated by the university researchers who benefit personally from affiliation with companies. Faculty find themselves able to improve their financial status through:

- participation in royalties on their inventions, (an explicit directive of Bayh/Dole);
- paid consulting to companies, particularly to companies that are sponsoring research in the faculty member's laboratory; and
- equity ownership in start-up companies.

In many cases, these potential areas of conflict have been resolved to the benefit of the universities, faculty members, and the companies with which they interact. Nevertheless, these relationships are evolving rapidly; new precedents are set each year; and universities must be vigilant in defending their fundamental educational and basic research missions.

As the Columbia University case illustrates (see Case Studies section), the leading research universities are well aware of the complex nature of university-industry research relationships. In this case, the real and potential benefits are clear for all parties: Columbia receives funding from the private firm (VIMRx Pharmaceuticals), VIMRx has access to potential knowledge that may translate into new products, and society may ultimately benefit from a faster innovation process due to the direct relationship between university and firm. The potential downside is also recognized by Columbia officials: the possibility that the traditional openness in dissemination of basic research findings will be threatened; the narrowness of single company relationships; and the influence on the overall balance of Columbia's research portfolio, potentially away from basic research. As a case study in progress, Columbia's relationship with VIMRx illustrates the benefits, costs, and unknowns of the research university's new role in the marketplace.

The Federal Laboratories

Although a vast majority of federal R&D is either not basic research or is performed outside of the government on a contract or grant-award basis, the government itself does perform basic research through the federal laboratory system. In 1995, for example, federal laboratories accounted for $2.7 billion or about 20 percent of federal basic research dollars (see Appendix Figure 6 in Appendix 1).[32] Historically, the federal labs have been a very important venue for basic research, generating many important discoveries and scientific insights in fields as diverse as the health sciences and nuclear physics.

The management structure of federal labs varies. Some are operated directly by the government (e.g., the National Institutes of Health, the National Institute for Standards and Technology, and the U.S. Geological Survey), while others are operated for government by private or nonprofit entities, including universities and other nonprofit organizations (e.g., Los Alamos, Oak Ridge, and the Jet Propulsion Laboratory). Among the largest of the 700 labs funded by the federal government are the so-called "national labs," administered by the Department of Energy and historically charged with energy and defense missions. These labs perform a mix of basic, applied, and development research and command substantial R&D budgets (see Figure 4).

Since the end of the Cold War, the missions of the Department of Energy national labs have been in flux. These labs have moved to deal with the problem of disappearing missions by seeking new "missions," often related to civilian technology needs and the international competitiveness of U.S. industries. For example, Intel, Motorola and Advanced Micro Devices recently announced a commercial research partnership with three national labs to develop computer chips using extreme ultraviolet technologies.[33]

Critics have charged that such efforts are wasteful of federal tax dollars, and that the number and size of labs administered by the Department of Energy are no longer justified by the mission of the agency that supports them. In the case of the computer chip partnership, there has been further criticism due to the potential for foreign firm participation in the project, which would amount to a federal subsidy of foreign companies.[34] This criticism highlights the political problems that can arise as agencies attempt to justify initiatives under the "national competitiveness" rubric.

The problems of many federal labs are not limited to their missions. Of all the institutions that perform basic research, the DOE labs are said to be the most lacking in flexibility and cost-efficiency,

Figure 4

Federal Obligations for Research and Development at the "National Laboratories"

	Fiscal Year 1995 (Dollars in Thousands)
Total National Labs	**$3,012,548**
Idaho National Engineering Lab	$77,745
Oak Ridge National Laboratory	$288,332
Sandia National Laboratories	$654,472
Argonne National Laboratory	$252,879
Brookhaven National Laboratory	$216,094
Ernest Orlando Lawrence Berkeley National Laboratory	$170,870
Lawrence Livermore National Lab	$500,622
Los Alamos National Laboratory	$102,278
Pacific Northwest National Laboratory	$208,529

SOURCE: National Science Foundation, *Survey of Federal Funds for R&D: FY 1995, 1996, 1997,* (data available at *www.nsf.gov).*

resulting from an overly-centralized, micro-managed resource allocation system.[35] Indeed, governance reform was a key area of concern in the 1995 Galvin Task Force, charged with advising the Secretary of Energy on alternative futures for the national laboratories.

Unlike the decentralized, competitive investigator-driven model that characterizes university research, administration of research at the national labs has been centralized, top-down (from within the Department of Energy and from Congress) and largely lacking in outside peer review. The Galvin Task Force reported that, while the DOE labs support a small amount of competitively-determined individual investigator research projects, "the research culture at many of the laboratories has been influenced by their relative physical and intellectual isolation and by a sense of entitlement to research funds."[36]

Despite all of these problems, the labs have considerable resources in the form of physical and human capital. Unlike the individual investigator work that typically characterizes university research, basic research performed at the national labs has often been performed on a much larger scale, with considerable physical capital investments made over many years. Critics and supporters of the labs alike now struggle with the question of how to put these large-scale resources to work, short of abandoning them altogether. This question has been the impetus for a number of blue-ribbon commissions in recent years.[37] Unfortunately none of these initiatives has produced a politically-viable consensus on meaningful restructuring.

Nonprofit Institutions

Basic Research at Nonprofit Research Institutions

Although they account for only seven percent of basic research in the United States, nonprofit institutions (that are not universities) perform a significant amount of basic research. In some cases, they provide a unique alternative to the dominant model of university-based basic research.

Many nonprofit research institutions are affiliates of universities, maintaining formal ties with the university but remaining independent of its non-research functions. The Whitehead Institute for Biomedical Research, an affiliate of the Massachusetts Institute of Technology, is one notable example.

Nonprofit institutions sometimes offer the individual researcher attractive alternatives to the predominant university basic research venue. Two noteworthy examples are The Howard Hughes Medical Institute (HHMI) and the Scripps Research Institute. HHMI offers much sought-after appointments for scientists, who are attracted by generous and stable financial support and a research environment that does not require time outside the lab devoted to fundraising. HHMI laboratories are located at research universities across the country; these universities serve as collaborators with the Institute. HHMI maintains the laboratory facilities at these universities and employs the scientist and all necessary support staff (including research associates and technicians). Scientists employed by HHMI are appointed to five or seven-year terms, with the possibility of renewal under rigorous standards of review. These terms represent a longer and more stable period of support than many university scientists are able to achieve through research grants from the federal government or other funding sources.

Scripps maintains its own research campus in La Jolla, California, also attracting eminent researchers through generous and stable financial support, affording researchers maximum time spent in the labs and away from fund-raising duties. Like the nation's research universities, Scripps relies on federal grants for a majority of its research funding, though it has aggressively pursued funding from industry and philanthropic sources. Unlike the academic research model though, Scripps does not isolate its faculty and labs into separate disciplines. Rather, it emphasizes cooperation and collaboration across disciplines.

Institutions like Scripps also present an interesting alternative to one aspect of the university-based training model for graduate students. Scripps offers graduate-level training in various research disciplines, but does not educate undergraduates. As the "teaching versus research" debate continues on university campuses, this alternative model—which couples basic research with graduate training, but excludes undergraduate teaching—may become more attractive for faculty scientists and graduate students.

Basic Research Funding from the Nonprofit Sector

Certainly, HHMI is tremendously important to basic medical research, not simply due to its unique administrative and performance structure, but also for the considerable financial resources it brings to the research enterprise. In fact, the nonprofit philanthropic sector has always been an important source of funding for research. HHMI is a relative newcomer: the Rockefeller Foundation and the Carnegie Institution have been important sources of such philanthropic support throughout this century.

As a funding source, foundations are very small relative to the federal government; yet, they can offer distinct advantages, which allow them to leverage their funds to greater effect. For example, foundations can move more quickly than the government to fund projects. In this way, they can act as a funding bridge, stepping in to maintain funding for important projects whose grants are about to expire. Foundations may also be more progressive than the government in valuing and funding cross-disciplinary research.

THE CRITICAL VALUE OF THE INDIVIDUAL RESEARCHER

As discussed in Appendix 1 (see Appendix Box 1, "Research Dollars Versus Other Inputs"), basic research in the United States is not adequately described by dollars spent. Nor can it be characterized only by the institutions that house it. In fact, the core strength of the research enterprise lies in the people who do the research. Indeed, the history of science and engineering and of the great discoveries is a history of individual scientists, whose names—James Watson, Jonas Salk, Linus Pauling—are often more readily recognized than their discoveries. The success of the American basic research system has rested in its ability to foster such creative minds and ensure a robust flow of new scientists through the education, training, and employment pipeline.

As we described earlier, a great strength of our basic research system is the symbiotic relationship between research and graduate education in the research university. The university scientist has in the institution's graduate students a pool of highly skilled and motivated labor. At the same time, the experience and training that the graduate student receives in a university lab ensures a stream of talented future scientists. The education function of the university—that is, the training of future scientists—is as important to the future of basic research as the research function itself.

Young scientists trained in the research university go on to careers in the university, government, and industry sectors. As Figure 5, page 28, indicates, a growing proportion of scientists and engineers are employed by industry, although in absolute terms employment in all sectors is growing (see Appendix Figure 3 in Appendix 1). Industry-employed scientists are an important link in the transfer of basic research to industry. In-house basic research expertise is often necessary even when little basic research is conducted within the company. Industry scientists play an important role in identifying and interpreting basic research performed outside of the company for use internally.[38]

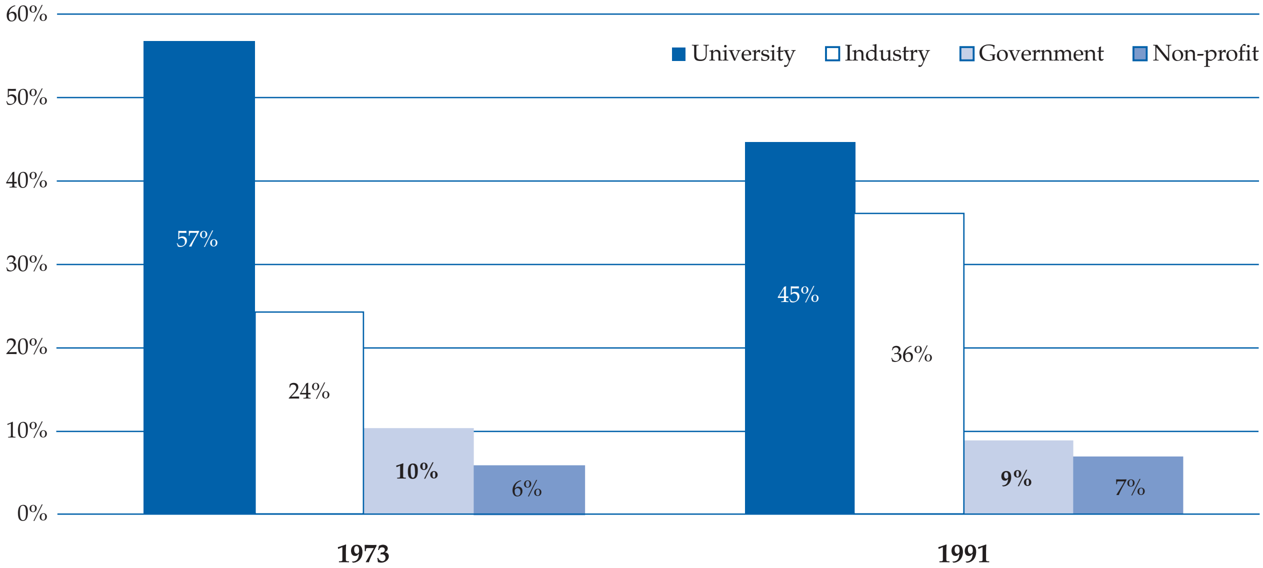
It remains, though, that much of the success of our basic research system lies in the ability of academic researchers, and particularly young academic researchers, to exploit the individual autonomy and freedom that their institutions provide them. The university environment fosters a spirit of independence and creativity among scientists that is hard to find in other organizations. This environment is particularly important for young scientists, who are given opportunities for advancement early in their academic careers that are rare in more hierarchical organizations. In short, the university research environment is able to recognize and exploit talent regardless of seniority. Consequently, the flow of new scientists into the university workforce has been an important dynamic in the basic research enterprise.

Yet, there are signs along the length of the "pipeline" of new scientists and engineers to suggest that the future quality of the human infrastructure for basic research is not assured. In order to assess our human capacity to do

Figure 5

Where Doctoral Scientists and Engineers Are Working

Distribution of Employment of PhD Scientists and Engineers by Employment Sector



NOTE: Percentages do not total 100 percent due to non-response and omission of the non-university education sector.
SOURCE: *Reshaping Graduate Education of Scientists and Engineers*, Committee on Science, Engineering and Public Policy, (Washington, DC: National Academy Press, 1995).

basic research in the future, we must consider the condition and quality of today's educational pipeline at all of its stages:

1. The poor performance of our K-12 students in the sciences is well-documented.[39] A recent survey reported that 43 percent of high school seniors have a below-grade level knowledge of science.[40] Further, evidence from international studies suggest that even our best students perform poorly relative to students in other countries in the sciences and math.[41] Poor performance in the sciences and mathematics (and all disciplines) during these early years not only effectively precludes many American students from later scientific training and employment, it also places an increased burden on universities and colleges to provide remedial education, at the expense of more sophisticated study in the sciences.

2. At the undergraduate level, the share of science and engineering degrees has declined over the past three decades.[42] Increasingly, many of our "best and brightest" are opting out of future careers in the sciences during their undergraduate years.

3. An important source of high quality scientists and engineers—foreign students—may be leveling off (see Figure 8, page 31) and is far from assured in the future. As other countries develop their own basic research capabilities, the supply of foreign students who train in the United States and remain here for careers in basic research should not be expected to match earlier decades, when there was a paucity of basic research performed in other countries (particularly in Asia).

4. The current system of graduate training has contributed to problems in the employment

of new PhD's and may have a discouraging effect on the number and quality of students entering graduate programs in the future:

- The time to degree for PhD recipients in the sciences has been rising, from 5.4 years in 1962 to 7.1 years in 1993.[43]
- The number of new PhD's entering post-doctoral fellowships and other temporary or part-time employment is also on the rise,[44] creating an increasingly unstable work environment during the critical early years of employment in basic research. In some fields, recent graduates have gone from a first to a second, and in some instances a third post-doctoral research grant while continuing their search for an academic position.
- Without adequate flexibility in training and in career counseling, new PhD's emerge from graduate programs into a very narrow, academic job market. While training for a career in academic research is critical to the quality of science and engineering PhD's, additional training to provide students with additional options upon graduation is also important.

5. Finally, the employment environment in universities for scientists and engineers is strained by the amount of time devoted to fundraising-related activities and away from the research lab.

All of these issues point to potential trouble spots in coming years. It is worth reaffirming, however, that these problems arise within a system of education and training for basic research that continues to perform very well, perhaps better than any other in the world. Nonetheless, as we discuss in the next chapter, all of the concerns we identify here should and can be addressed today, long before small problems become big ones.

THE INTERNATIONAL CONTEXT FOR AMERICAN BASIC RESEARCH

The 20th century has seen the United States rise to a position of global preeminence in generating new knowledge. World leadership in innovation has been viewed as both a cause and a consequence of the nation's economic success on the world stage. But it appears inevitable that as other nations develop their innovative capacities, the United States will become less dominant in various scientific disciplines and economic sectors.

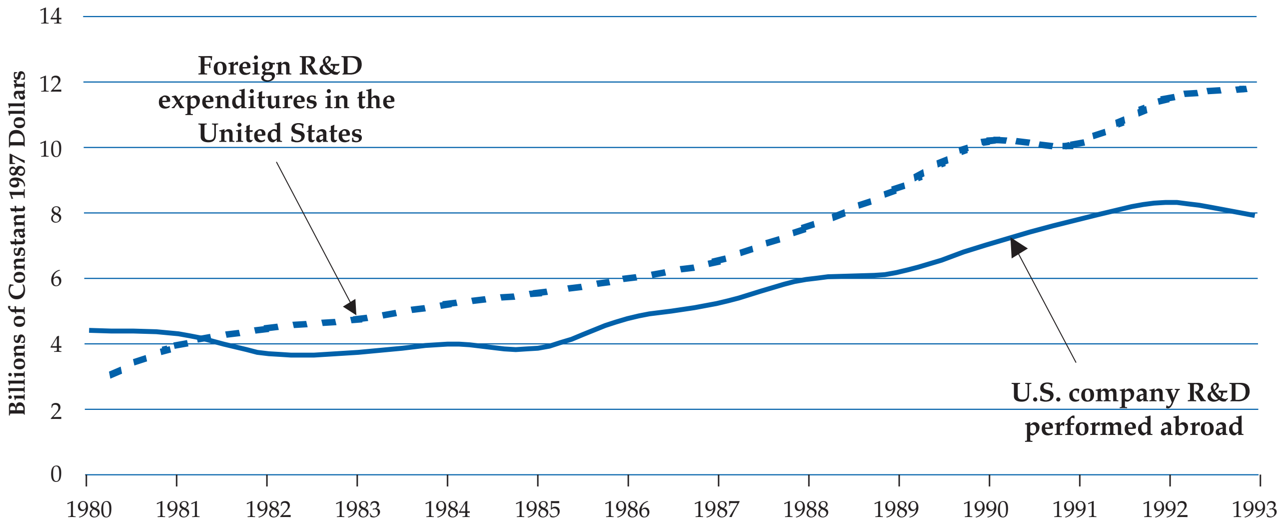
Recent trends suggest that while the United States continues to be the world's leader in the generation of new knowledge, other countries are contributing more than in the past. The U.S. share of all scientific and technical literature worldwide continues to be much larger than any other country's, but it has declined slightly in recent years from 36 percent in 1981 to just under 34 percent in 1993.[45] Most of that decline can be attributed to Japan's increasing share.

It would be a mistake to view these trends as a threat to the United States. As basic research activities grow worldwide and the global stock of new knowledge increases, all countries benefit. Further, other countries are increasingly our collaborators in basic research. Cross-national collaboration in research, facilitated by rapid advances in information technology, is a growing phenomenon and an increasingly important mechanism for pooling resources for large basic research projects. Figures 6 through 8, pages 30 and 31 illustrate three measures of this trend.

- As Figure 6 indicates, foreign R&D expenditures in the United States have grown dramatically since 1980; R&D performed abroad by U.S. firms has also increased, though at a slower rate.
- As a share of total national science articles, internationally co-authored articles have increased for all of the leading industrial countries (see Figure 7, page 30).
- Finally, the number of foreign graduate students in academic research programs in the United States has increased 75 percent since 1980, although as a share of all graduate students, their numbers have increased only slightly over this period and their share is now declining (see Figure 8, page 31).

Figure 6

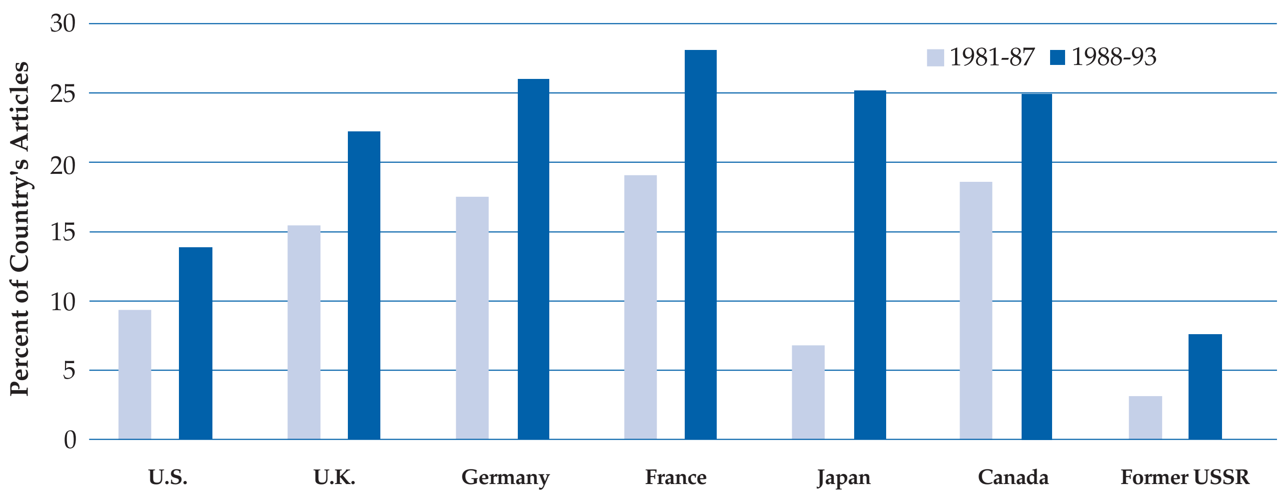
Increasing Cross-National R&D Investments



SOURCE: National Science Board, *Science & Engineering Indicators, 1996.* Washington, DC: U.S. Government Printing Office, 1996).

Figure 7

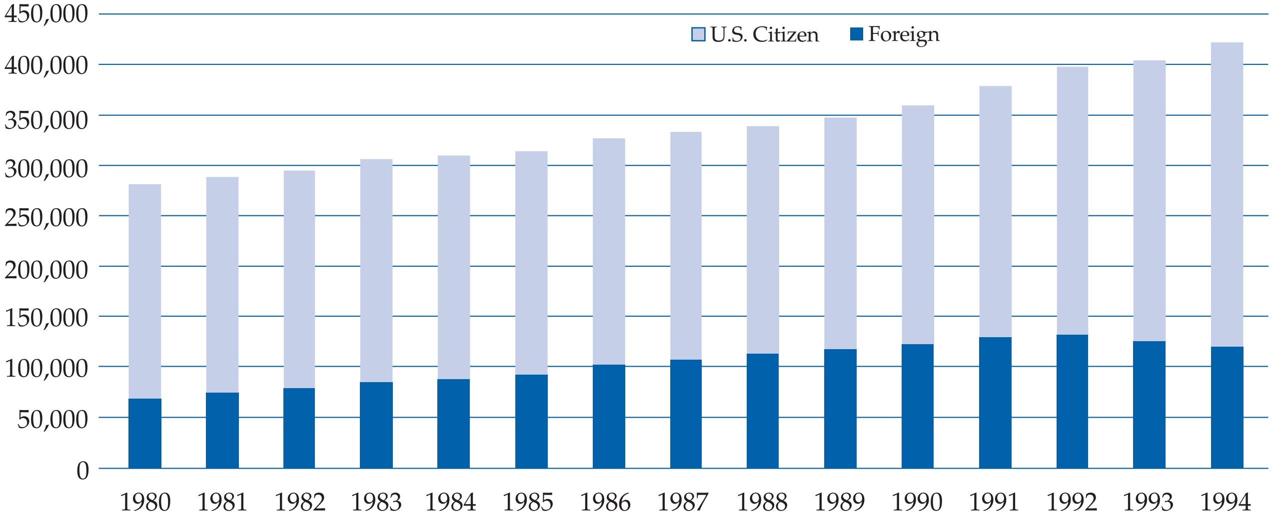
Internationally Coauthored Articles, Selected Countries



SOURCE: National Science Board, *Science & Engineering Indicators—1996*, (Washington, DC: U.S. Government Printing Office, 1996), Appendix Table 5-34.

Figure 8

Full-time Foreign and U.S. Graduate Students in Science and Engineering Fields in U.S. Universities



SOURCE: National Science Foundation/SRS, *Survey of Graduate Students and Postdoctorates in Science and Engineering* (data available at www.nsf.gov), Table B-5.

Some observers have questioned the ability of the United States to capture the return on its research investments in an increasingly global economy and scientific community. For example, the growing number of foreign graduate students who leave the United States upon graduating has provoked concern in some quarters. But it is not at all clear that the U.S.-trained foreigner who returns to his or her country represents a net loss to the U.S. economy. After all, much of the value of the U.S. research university is derived from the work performed by graduate students during their enrollment in the university. Further, U.S. industry benefits from research undertaken abroad, often performed by American-educated scientists and engineers.

CONCLUSION

Basic research in the United States is unquestionably one of the great success stories of the past 50 years. Indeed, the basic enterprise described in this chapter is strong and effective. But to maintain, and even build on, this enterprise for the next 50 years, there are problems to address. From how federal policymakers allocate funds for basic research, to how individual researchers balance their research and teaching responsibilities with the demands of fundraising and entrepreneurship—these issues set the agenda for policymakers and business leaders concerned about basic research and will guide the discussion of policy recommendations in the next chapter.

Chapter 4

MAINTAINING U.S. LEADERSHIP IN BASIC RESEARCH: THE CED PRESCRIPTION

The remarkable scientific progress that has helped to define 20th century America is due in no small part to the unique characteristics of our basic research enterprise. Chapters 2 and 3 have described these elements of success in American basic research— public funding, merit-based allocation of resources, the central role of the research university, the primacy of the individual investigator, and a robust education pipeline for future scientists and engineers— and how they have contributed to the social and economic benefits that we enjoy today. But in each of these elements there are currently signs of stress that need to be addressed if the promise of tomorrow's basic research is to meet the expectations created by the successes of the past. In this chapter we will describe the challenges to our system of basic research, offering policy recommendations that address:

- problems in the way resources are allocated for basic research
- the threats to ensuring adequate resources for future basic research
- the challenges of maintaining a pipeline of high-quality scientists and engineers into the basic research system
- the potential conflicts and problems arising from the increased interaction between universities and the marketplace
- the challenges that American basic research faces in an increasingly global economy and research enterprise.

IMPROVING THE ALLOCATION OF RESOURCES FOR BASIC RESEARCH

In addition to ensuring an adequate level of resources for basic research, policymakers have a responsibility to maximize the potential of those resources through efficient allocation mechanisms. There is waste and inefficiency in the current allocation systems for basic research. Shortcomings in allocation arise on two levels: 1) in the allocation of the research grant from the funding agency to the researcher, whether it is done competitively, based on peer review, and whether it is directed toward individual investigators rather than institutions; 2) in the allocation of funds to agencies and missions from Congress.

Mechanisms to Ensure Quality in Funding

If basic research were like any other production process, efficient allocation of resources would be a relatively straight-forward matter. Resources would go toward efforts that demonstrated the highest productivity, as calculated through a measure of output. But as described in Chapter 2, measuring research outputs and the productivity of basic research in general, let alone for individual basic research projects, is highly problematic.

Over the years, government agencies under various mandates have attempted to develop output measures and related productivity and quality indicators for federally-sponsored research. The most recent initiative has been mandated by

Congress under the auspices of the Government Performance and Results Act (GPRA). GPRA requires all government agencies to submit performance plans for measuring and assessing program impacts as a means of increasing public accountability, an exercise that has proved understandably problematic for science and research-related programs. Efforts to increase accountability in government are laudable and government-funded basic research should not be exempt. Nonetheless, GPRA should not impose one-size-fits-all criteria for measuring results. Such an approach would, at best, prove unworkable for basic research programs; at worst, a rigid imposition of quantified performance standards would undermine basic research by shortening the timeframe of projects and limiting their scope to areas where the payoff is predictable at the outset.

Measuring basic research output is no less a troublesome issue for business, which companies have addressed with mixed success. The IBM case (see Case Studies) highlights that company's efforts to quantify its own research output, measuring for example, number of patents filed, number of external awards received by IBM researchers, and self-assessments of key results for the year.

Absent meaningful and practical output measures, we must rely on other means of efficiently allocating resources. The best alternative, we believe, is the system of peer-reviewed competition for research grants. Peer-reviewed awards to individual researchers— and increasingly to teams of researchers— for individual research projects helps to ensure quality on a project-by-project basis. Some critics have charged that peer review encourages an "old boy" network because it favors the status quo in grant awards. Yet, we know of no better mechanism for emphasizing substance over reputation or political interests.

The worst abuse in the allocation of basic research dollars, leading to the least productive use of research funds, is Congressional earmarking. The most recent survey of these activities demonstrates dramatic growth in the number of earmarks for academic research in recent years.[46] Figure 9, page 34 shows the increase in number of earmarks during the 1981-1992 period; over the course of a decade, academic earmarks increased in value from the tens to the hundreds of millions of dollars. Such earmarks frequently place narrow constituent interests or even otherwise laudable goals like regional economic development, over scientific merit.[47] **In bypassing the competitive, peer-review process for determining merit, earmarking for basic research is a form of pork-barrel, like any other; it should be recognized as such and acknowledged to have no place in our publicly-supported basic research enterprise.**

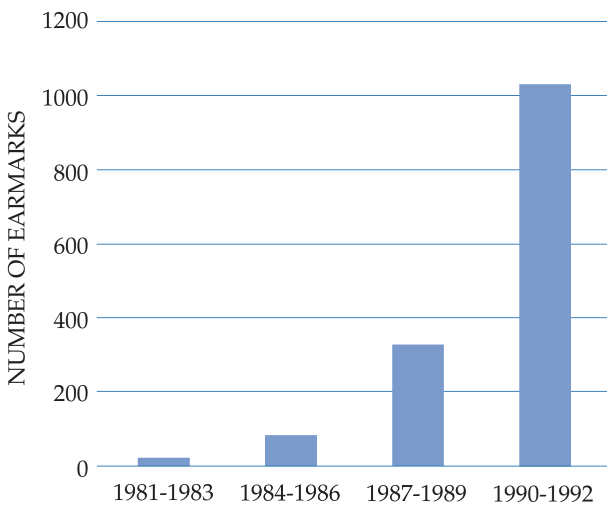
Of course, allocation of funds through peer-reviewed grants to individual investigators does not meet all the needs of our basic research enterprise. For example, there has long been, and continues to be, a need for public investments in large-scale projects, often referred to as "big science."[48] Historically, projects like the fusion reactor at Princeton University, the historic Voyager satellite missions, and NSF's deep sea drilling project have proved very important to basic research and could not have proceeded in the context of relatively small individual investigator grants. **In cases such as these, when the nature and size of the research project makes individual investigator grants impractical, direct funding of institutions rather than individuals is appropriate.**

Unfortunately, because of the large institutional and regional economic stakes, funding for big science often falls prey to political interests. Also, it is often threatened by budget cuts or other outside attempts to influence the character of the project. **It is the responsibility of policymakers to ensure that necessary investments in big science and institutional grants proceed on the basis of scientific merit (determined by expert advisory committees) and in the larger context of national needs and priorities.**

Further, it is important to emphasize that allocation for big science through institutional grants simply means investing in the infrastructure necessary to make certain fields of inquiry possible by giving researchers the tools to do their work. **The scientific work that proceeds from investments in these tools should conform to the same process of competitive peer review that individual investigator projects do.**

Figure 9

Growth in Number of Congressionally-Earmarked Academic Projects



SOURCE: National Science Board, *Science & Engineering Indicators—1993*, (Washington, DC: U.S. Government Printing Office, 1993), p.139.

In sum, the primary mechanisms for allocating federal basic research funds in all agencies and to all institutions—whether universities, federal labs, or elsewhere—should be based on scientific merit determined through peer review and the support of individuals and projects. Political earmarks for basic research are an unproductive use of scarce funds and should be halted. The needs of big science can be met without sacrificing scientific quality, but this depends critically on the motivations of policymakers and the input of scientists.

Ensuring Adequate Funds for All Basic Research Disciplines

Peer review goes a long way toward ensuring quality in the allocation of funds from federal agencies to individual research projects. But at the start of the funding stream—the allocation of basic research dollars from Congress to federal agencies—there is no such mechanism to ensure overall quality. **Setting broad priorities in basic research is the domain of policymakers in Congress and the Administration, and should be the result of informed policy debate.** Scientists have an important role to play in ensuring that the debate is an informed one; but ultimately, these decisions are appropriately made by our elected leadership.

Certainly, as the growth in earmarking illustrates, there is room for improvement in how priorities are established in public funding for basic research. CED does not believe an overhaul of the congressional appropriations process in order to serve the needs of basic research is practical or remotely likely. Just the same, Congress can act in a number of ways to ensure quality basic research in its appropriations. **We believe it critical that Congress work to achieve a balance among basic research missions, a diversity of missions, and that increasingly important cross-disciplinary research receives better treatment by congressional appropriators and agency administrators alike.**

Balance in Basic Research Missions

Currently, the health mission dwarfs all other categories of federal support for basic research (see "Life Sciences," Appendix Figures 7 and 10).[49] Although we recognize that missions must be prioritized to ultimately reflect the needs of society at large, we also believe that neglect of less popular areas of research is foolhardy. Health research has benefited immeasurably from advances in the computer sciences, the behavioral and social sciences, mathematics, and physics—yet these disciplines receive most of their federal support from non-health missions. The defense mission, in particular, has been an important, and in some cases a primary, source of funding for diverse scientific disciplines (see Appendix Figure 12). But, the decline in funding for this mission alone from its Cold War levels has had negative consequences for some areas of basic research.

While the health sciences have clearly benefited from applications of advances in other disciplines, various non-health fields of science have, in turn, been furthered by biomedical research. In addition, the needs of biomedical science have created demand for further research in other fields such as chemistry, physics, materials and engineering, and information technology.

These observations underlie the concept that basic research and subsequent development is a mutually reinforcing process occurring between a variety of science and engineering fields. All of these fields will require adequate support in an increasingly multi-disciplinary environment.

The agency missions themselves are dependent on many scientific disciplines. Ultimately, progress in any single field will not be sustained if other fields whither on the vine. **In order to achieve an appropriate balance in funding for scientific disciplines, appropriators need to pay close attention to the impact of agency and mission funding decisions on specific scientific disciplines.** As some missions become lower priorities in the federal budget (the post-Cold War defense mission), or as Congress pursues structural reforms in major programs tied to basic research,[50] the impact (direct or indirect) on scientific disciplines should be assessed and those disciplines should be accommodated in a way that is consistent with mission/agency goals and the needs of basic research generally. Often, this may mean making basic research funding a higher priority in other missions and agencies (such as the NSF), as it becomes less of a priority in declining missions (as in defense).

A Diversity of Missions

The National Science Foundation has long been a model of support for peer-reviewed basic research independent of agency missions at the federal level, providing funds on the basis of merit to the entire spectrum of science and engineering disciplines. Nevertheless, much of the scientific progress of the past half-century resulted from much larger allocations to basic research funded by the Department of Defense and the National Institutes of Health. Consequently, any effort to abandon agency and mission-based support for basic research in favor of the "secular" efforts of the NSF would ultimately reduce the amount of public support for basic research in general and undermine the value of a diverse approach to funding. **Federal support for basic research should be diverse in its funding sources, resisting efforts for central control or concentration in one mission area. The diverse model is most viable politically and is best-suited for the unpredictable nature of basic research outcomes. Therefore, we do not support calls for a "Department of Science" or for an NSF that would envelop all other federal sources of basic research support.**

Cross-Disciplinary Research within Missions

All sources of federal basic research funding should recognize the cross-disciplinary imperative of much of today's basic research and encourage such approaches in their funding decisions. The case studies (and particularly the Pfizer, Merck, and Harvard cases) provide compelling evidence that a cross-disciplinary approach to scientific investigation is a necessity in many areas of research today and is an approach employed successfully by businesses and universities alike.

It is not enough to ensure balance among missions; it is increasingly important to recognize research that must take place across funding missions and across scientific disciplines. Grant proposals that fall outside of the traditional categories or scientific disciplines should not be punished by a traditionally discipline-oriented funding structure and peer review bias. This is an imperative that applies to universities and peer review panels as much as it does to agency administrators and congressional appropriators. Evaluating merit in these cases may require more effort (requiring, for example, a peer review panel that consists of scientists from more than one discipline). But the effort should be made. Universities can promote collaboration by recognizing its value in tenure decisions and through university-level initiatives that are independent of federal agency directives. Harvard's Mind/Brain/Behavior program (see Case Studies) illustrates such an initiative.

Keeping Research Universities at the Core of American Basic Research

The Central Role of the Research University

CED believes the most productive use of federal basic research funds institutionally is

through the nation's research universities. The universities' exceptional track record in performing high-quality basic research is not surprising given the central role of the individual investigator and the widespread use of competition in grant awards.

The research university deserves to be the predominant basic research institution in America for yet another reason: federal support of university research ensures the future health of science and engineering by supporting the training of graduate students (see "Sustaining the Education and Employment Pipeline," page 40). Tomorrow's scientists and engineers receive the best possible training in today's university research laboratories through direct participation in the leading research of the day. There simply is no substitute for this type of training. A decline in support for research universities would terribly weaken the foundation for the basic research enterprise of the future.

Problems and Solutions in the Administration of Federal Grants for University Research

Although federal funding of basic research in universities has been very successful, there are several aspects of the grants process that are problematic—for the individual researcher and the university—and should be reformed.

There are concerns among many university researchers that the competitive grant structure has become overly-burdensome for the individual researcher and has deterred young scientists from pursuing careers in academic research. The administrative burden for the individual researcher lies in: 1) short-duration grants, which require repeated preparation and re-submission of grant applications to sustain research projects; 2) the low rate of success in applications; 3) the long time period between the submission of applications and the notification of awards; 4) the very high dependency of the individual investigator on external support and the lack of seed money. **To alleviate these problems we urge grant-making agencies (and universities) to review their requirements and systems of support with an eye toward reducing administrative burden.**

Grant-making agencies should explore ways to offer outstanding scientists longer-term grant support, to provide young researchers with sufficient resources to launch their careers, and to ensure that established researchers who temporarily lose grant support are not forced to abandon long-term, productive research endeavors. Institutions like the Howard Hughes Medical Institute and the Scripps Research Institute (see Chapter 3) provide cues for grant-making institutions and universities in this effort. In particular, we urge agencies to consider extending the funding period of their basic research grants. The continual process of applying and re-applying for grants has a very discouraging effect on young scientists and engineers considering careers in university research. Longer and more stable periods of grant support would alleviate this problem

Many funding agencies have already begun the process of limiting administrative burden in grant awards and have made some progress. For example, some agencies now permit electronic submissions of grants. However, a large and persistent cause of administrative burden results from a cumbersome system of overhead, or indirect cost, reimbursement in the federal grants process. Federal research grant awards to university researchers include funding to cover the direct costs of the research and overhead research costs incurred by the university, reimbursements for which vary considerably from grant to grant. From the university's perspective, there are large costs associated with the investments in plant, equipment, and human resources necessary to pursue individual research grants and sustain a research enterprise at the university. The universities' tuition income and other funds received for education are designated strictly for that function. Without overhead reimbursement, universities would not have the necessary level of resources or incentives to sustain a vibrant basic research enterprise.

But the current retrospective, cost-based procedures for establishing federal reimbursement for overhead have resulted in a fractious relationship between universities and government. Present procedures are very costly and time consuming and, according to some experts, distort incentives for efficient expenditures.[51] To remove these distortions, and much of the unnecessary regulatory burden, they recommend a system in which overhead rates associated with all research grants are set by benchmarks, or average overhead rates for similar universities. The benchmarks would be determined on a periodic basis by examining costs at a small sample of universities within each class of institution. Such a procedure would greatly reduce accounting and auditing costs for universities. It would also minimize government leverage, which universities consider excessive because of the government's power to demand lower reimbursement levels. Indeed, universities have argued forcefully that cost-shifting has escalated in recent years, with federal agencies increasingly unwilling to adequately cover overhead costs. Finally, benchmarking would provide universities with a strong incentive to trim overhead, because they would benefit from holding costs below the benchmark.

CED believes that the benchmarking of overhead reimbursement rates has merit in principle and encourages funding agencies and universities to explore it on an experimental basis. The determination of "similar universities" is a difficult task, which should take into account geographic variations among other factors. In general, reform of indirect cost reimbursement should be guided by the principles of fairness (to both parties) and simplicity.

Too Many Research Universities?

Some observers are concerned about the number of research universities vying for federal funds today (see Chapter 3). As this number grows, basic research resources are spread more thinly and may be put to less effective uses. We recognize this possibility, though **we do not support attempts to set a fixed number of research universities eligible for funding, or worse yet, a fixed list of specific universities eligible for funding.** Historical experience indicates that it is very difficult to predict who will make discoveries and where discoveries will take place. Further, such "fixes," in our minds, violate the principles of flexibility and competition that have defined the success of America's university research system.

CED believes the appropriate number of research universities will best be determined by reinforcing existing mechanisms of peer review, as well as by distributing funds at the project and investigator levels rather than at an institutional level. Competition for grants based on scientific merit will ultimately separate the wheat from the chaff among universities. Those that do not attract quality researchers will not be able to support a research program through federal grants. And the openness of the competition to researchers regardless of institutional home ensures accessibility to high talent wherever it is based.

Unfortunately, university research that is funded outside of the peer review system is not subject to this important competitive process. Again, political earmarks are not an appropriate funding mechanism to support universities or any other research institution. University research supported by earmarks would not likely meet the peer review standard, and a proliferation of research universities due to earmarks would undermine the quality of our basic research enterprise.

Finally, although we do not support a "top-down" approach to limiting the number of research universities, **we also do not believe that all universities and colleges in the United States should feel an entitlement or an obligation to pursue federal research dollars.** Competition for research dollars is healthy for the basic research enterprise; it is not always in the best interest of individual universities and colleges to enter this competition. **In particular, schools should not neglect their education mission in the process. For many institutions, the pursuit of a research function comes at the cost of undergraduate education, which is critical not only to the basic research enterprise but to our economy and society as a whole.**

Existing Alternatives to Research Universities Are Weak

Although CED supports basic research funding through a diversity of missions and agencies, we question the degree of success that some agencies have had in supporting basic research. We believe that the further removed agencies are from a merit-based, competitive grant system of allocation, the poorer the science will be which they support. The quality of research supported by the Department of Agriculture has suffered for this reason.[52] In fact, just 5.4 percent of the Department of Agriculture research budget goes to nationally competitive research grants. If payoffs to our public investments in agricultural research are going to improve in the future, this percentage must increase substantially.

The Department of Energy's national labs face an uncertain future due, in part, to inadequate mechanisms for determining merit, but also due to shifting missions. It would be a mistake to view the end of the Cold War as the end of the mission justification for the national labs. There remain very strong defense and energy research objectives that are within the purview of many of these labs. However, at the prodding of the Administration and Congress, many labs are increasingly chasing the technology *du jour*, with over half of their research dollars now devoted to commercial product development, often through industry partnerships.[53] Although industry partnerships with the national labs may serve the competitive interests of specific industries in the development and commercialization of technologies, they do not always serve the interests of the nation and its taxpayers. As we argue later in this chapter (see "Choosing Basic Research Among Competing Claims," page 39), **subsidizing civilian technology for national competitiveness purposes is not a justifiable federal mission and it should not be allowed to displace federal investments in basic research.** Further, the Intel case described in Chapter 3 illustrates the political morass that such partnerships can create when mission justification is weak, raising questions of favoritism among companies, as well as concerns about indirect federal subsidies of foreign companies.

At the same time, the national labs continue to represent a tremendous potential resource for the nation's basic research enterprise, particularly oriented toward large-scale scientific inquiry. **We call on the Congress and the Administration to make a clear determination of the missions of the labs and assess where realignments of missions and functions are necessary.** The recommendations of the Galvin Commission (see page 26) should serve as a starting point for this work. The labs themselves should be free to take actions to ensure the best researchers are attracted and retained to accomplish lab missions. In particular, more of the research conducted in the national labs, including the large-scale science that they have the capacity to perform, should be brought into a system of competitive, merit-based peer review that characterizes the best of our basic research enterprise.

Beyond scientific merit and mission justification, cost-efficiency in these labs must be improved; performing basic research in the national labs should not cost more than similar projects in other basic research institutions. To this end, research projects performed in the national labs should be free of the multiple layers of micromanagement emanating from the Department of Energy and Congress that have created gross inefficiencies and rigidity in the labs.

In sum, it is clear to us that if the national labs are to continue to play a productive role in basic research, that role must be justified on the basis of strong missions, outside peer-reviewed determinations of scientific merit, and efficient management and oversight structures.

PRESERVING OUR CAPACITY TO DO BASIC RESEARCH IN THE FUTURE

Future capacity to do basic research requires long-term thinking today. Unfortunately, two threats to tomorrow's basic research enterprise currently command too little attention from political leaders and policymakers.

One is funding for basic research. Today's federal budgetary environment, with rosy scenarios for "budget surpluses as far as the eye can see," has created a decidedly optimistic attitude within the science and engineering community (and among its advocates in Washington). Speaking of a threat to basic research funding in this environment may strike many as odd if not downright foolish. Yet, the likelihood of stable and adequate support, not just for the next few years but for the next few decades, is far from ensured.

The second area that requires long-term thinking today is in sustaining the human capacity to do basic research. Sustaining the education and employment pipeline for basic research also means raising the technical and scientific ability of all students and society at large. This effort is important both so our citizenry can better exploit the increasingly flow of new knowledge in an increasingly sophisticated workplace and also so the importance of basic research is not lost by a society that is less connected to progress of science.

Ensuring Adequate Resources for Basic Research

Throughout this chapter we recommend ways that basic research resources can be used more productively. But none of these policy recommendations should be taken as support for getting along with less public support. As we described in Chapter 2, the economic and social payoff to American investments in basic research has been tremendous in this century alone. **Given this level of benefit, adequate and sustained funding for basic research must be a high and consistent national priority.**

With this in mind, we are deeply concerned by trends that have the potential to squeeze the level of resources for basic research in the future. Both the Administration and Congress now claim a desire to increase basic research funding substantially over the next few years. It remains to be seen, however, how these increases will materialize and if they will be sustained. Windfalls derived from a booming economy or a hypothetical tobacco settlement would certainly be welcome additions to basic research funding. They do not, however, eliminate political and budgetary imbalances that stand as threats to future funding.

Recognizing the Role of Private Sector Support for Basic Research

Advocates of a smaller government role in basic research point to increasing private sector R&D budgets as evidence that the federal government's efforts are no longer as important in this area. Industry is doing more, the argument goes, therefore government can do less. However, private spending on total R&D should not be confused with spending on basic research, nor should industrial basic research be confused with government-supported basic research. As indicated in Chapter 3 and as the Pfizer case study suggests, although the "Web of R&D Innovation" is a complex one, with complex interactions between basic and applied research, it remains clear that the private sector role in basic research, and in R&D in general, is and will continue to be largely distinct from the government's role (also see Box 2, page 12).

In sum, industry will continue to support and perform important areas of basic research; but this work should not be viewed as a substitute for the much larger role of the federal government in support of basic research. Given these trends and the misunderstanding of them that is prevalent among some political leaders and the public generally, we urge business to begin a dialogue with political leaders and the American public so that they might better understand the critical importance of steadfast government support of basic research.

Choosing Basic Research Among Competing Claims

Meeting the Entitlement Threat

Despite robust political support for short-term funding increases, support for basic research is likely to become less sure in years to come, due to the budgetary costs of an aging population. Basic research is one of many competing claims on a shrinking discretionary portion of the federal budget, necessitated by rapid expansion of entitlement programs, particularly Social Security, Medicare, and Medicaid. The considerable revenue boost the federal budget has received from the current expansionary economic cycle does not erase the underlying structural deficiencies in the budget. This is a problem that will become dramatically worse the longer we wait to deal with it; indeed, we may ultimately face devastating cuts in the basic research budget if entitlement spending is not brought under control before the baby-boom generation retires. **As CED has argued frequently in recent years, our political leadership simply must deal with the growing burden of the federal entitlement programs.**[54] Otherwise, the federal budget will have no room left for government's most important activities, including investment in basic research.

Federal Funding for Civilian Technology

One of the competing claims that basic research faces in the federal budget comes in the form of spending on applied and development research, much of which is necessary to achieve objectives in various missions, such as the development of weapons systems technology for national defense. A significant initiative of recent years, however, has been to seek to improve the international competitiveness of U.S. industry by increasing federal expenditures in certain areas of applied research and civilian technology development. The Advanced Technology Program in the Department of Commerce is a product of this initiative.

CED does not believe that national competitiveness programs have the same strong claim to federal support that basic research does. In Chapter 2, we described the very compelling case for government support of basic research. Although proponents of competitiveness programs often use the same language to make their case—that public subsidies are necessary to correct for insufficient levels of funding by the private sector in key areas (i.e., "market failures")—we find the case far from convincing. Indeed, too often government spending on programs of this type amounts to little more than taxpayer subsidies for favored industries and firms, supporting research that the private sector would have supported on its own or research that is not worthy of public *or* private funding.[55]

With few exceptions, we do not think government should be in the business of directly funding what we view to be a function of the private sector—development and commercialization of technologies. The exceptions apply in cases where the funding can be viewed strictly as a procurement function, as in the national defense example, or to correct a clearly defined and well substantiated market failure.

Finally, CED believes that the government should be sensitive to the basic research activities occurring in industry and should avoid duplicative initiatives. Federal funding is most vulnerable to duplication when research initiatives are overly-prescribed—as in research that is targeted at specific diseases—and removed from a general peer-review process.

Sustaining the Education and Employment Pipeline

In addition to the funding of basic research, a second threat to our long-term basic research capacity lies in our ability to sustain a pipeline of future scientists and engineers, a work force adequately skilled in the sciences to exploit new knowledge, and a citizenry with enough understanding of basic science to recognize its importance and support its progress.

The United States is not in danger of running out of scientists and engineers to perform basic research any time soon. After all, they comprise only a tiny fraction of the nation's work force: in an American labor force of 132 million, just 542,000 are doctoral scientists and engineers.[56] But there is a growing disconnect between the need for a highly-skilled basic research labor force on the one hand, and the quality of our K-12 math and science education and the interest in science at the undergraduate level on the other hand. Further, the desirability of basic research employment at universities is eroded by the amount of time devoted to applying for and complying with federal grants, as well as the demands of university technology transfer offices. Left unchecked, we are concerned that these trends will gradually erode the base of American students willing or able to enter basic research careers.

These trends also exacerbate the on-going challenge of attracting women and minorities to training and careers in basic research. The severe underrepresentation of these groups in the science and engineering disciplines has far-reaching effects on our basic research enterprise; in part, in contributes to concerns that the peer review process is biased against some researchers and research projects. **A more diverse research enterprise has been identified as a priority by uni-**

versities, agencies, and science organizations; we support this goal and urge these institutions to hasten its realization.

Finally, we are also concerned about a society that is increasingly isolated from the world of science and discovery. To a large extent, this isolation is driven by science itself. Long gone are the days when a well-educated citizen could be expected to have even a cursory grounding in all areas of knowledge (scientific or otherwise). But the isolation we are particularly concerned about involves a lack of understanding and acceptance of scientific methods and principles. This deficiency is a detriment to the skill needs of today's workplace. It also threatens to undermine the public support for basic research, an enterprise that relies primarily on the public sector for support. If society becomes less enthusiastic about science and more suspicious, or simply indifferent, the case for research support will become much more difficult to make in the halls of Congress.

Based on all of these concerns, we offer the following recommendations to strengthen the science education and employment pipeline and science education in general, not only for future scientists but also for a public that must ultimately support them.

Better Math and Science Education at the K-12 Level

In a series of policy reports on educational improvement, CED's trustees have done extensive research into strategies for raising academic achievement in general and science and math performance in particular.[57] The complexity of this task requires comprehensive and coordinated change in several interdependent areas:

- establishing national mathematics and science performance standards and assessing progress based on these standards;
- increasing teacher knowledge and skill through better training and more incentives;
- upgrading classroom curriculum and teaching methods, including but not limited to expanded use of technology in the classroom and adequate investments in infrastructure, such as lab space.

We maintain our strong support for high achievement standards at the national level in all core academic subjects, with particular emphasis on mathematics and science. However, given the inherent difficulties in getting national standards in these subjects developed and accepted, we urge teachers and administrators to actively and continuously pursue information and research on new knowledge and effective, innovative classroom practices and to redirect the mission and goals of their schools toward raising standards for student performance.

Improved learning cannot happen without improved instruction. **Therefore, our schools need to both attract and continuously support better-qualified math and science teachers, particularly at the middle and high school levels.** Strategies to accomplish these ends include:

- improving the way teachers are educated in college, which includes requiring prospective teachers to learn how to integrate technology use and project-based learning into the curriculum and requiring a math and/or science major for teachers who plan to teach at the middle or high school level;
- raising certification standards to require middle and secondary science and math teachers to have majored in their subjects and elementary school teachers to have taken substantive coursework in these subjects;
- employing stronger incentives, such as differential pay, to attract more qualified science and math teachers;
- developing alternative certification practices to allow experienced scientists and mathematicians from industry to enter teaching without having to spend unnecessary time in formal pre-service training, as long as they can demonstrate their teaching skills;
- encouraging businesses and other organizations that employ scientists and engineers to offer summer internships to teachers, giving them direct exposure to math, science, and technology in the workplace. These organizations should also explore opportunities to make their scientists and engineers available for

in-school and after-school sessions with teachers and students to help them keep up with changes in knowledge and practice in technology and science-related fields (see Box 4 for two examples in practice).

Finally, it is critical that students be actively engaged in learning in the sciences and math. **We believe that improved teaching methods, together with currently available interactive learning technologies, including computers and Internet connections, can effectively motivate student performance and accelerate improvements in learning. Substantial investment in infrastructure improvements are also critical in this regard—many schools have little or no lab facilities to support science instruction.**

In order to further engage students in learning and to excite students about a possible career in the sciences, they should have the opportunity to interact with members of the research community. **Businesses, universities, and schools should work together to place more professional scientists and engineers in the classroom as volunteers to assist in class lectures, lab work, and field trips.** These volunteers raise

BOX 4

BUILDING TIES BETWEEN PROFESSIONAL SCIENCE AND THE SCHOOLS

The Carnegie Institution of Washington and the New York Academy of Sciences are both active in addressing the shortcomings of K-12 math and science education in the United States. Their strategies reflect the key areas of concern: that math and science instruction be adequately substantive and that the instruction be engaging enough to spark students' interest in the subject matter.

Under the leadership of Dr. Maxine Singer, the Carnegie Institution launched the five-year Carnegie Academy for Science Education (CASE). Now in its fourth year, CASE provides teachers in the District of Columbia (350 to date) with intensive training in fundamental scientific and mathematical concepts. CASE attempts to re-train teachers whose standard training typically does not include sufficient grounding in science and math.

CASE recognizes that increasing the substantive knowledge of teachers is half the battle. How teachers impart this knowledge to students is also important. The Summer Institute of CASE emphasizes a pedagogy based on experimentation and questions, rather than rote answers and memorization. Teachers participating in the Summer Institute are engaged in the same experiments and exercises that they will later pass on to their students—for example, constructing the perfect recipe for chalk, testing the city's drinking water, or building wind-powered land racers.

The New York Academy of Sciences coordinates a summer internship program in the sciences for New York City school students. The program places students in research labs (university, government, and industry) alongside professional scientists. The defining element of the internship is the mentor-student relationship, which gives the students access to the world of scientific research through the eyes of a scientist. Students also participate in lectures, workshops, and discussion groups, all intended to help them assimilate the knowledge derived from the lab experience. The internship culminates in a research paper containing all the elements of a professional document.

Both of these initiatives make welcome contributions to science education. Both also demonstrate the importance of an organizational "broker" in developing ties between the research community and the local school system. One-on-one efforts by individual scientists to assist teachers or mentor students are laudable, but can only hope to have a large-scale impact in the context of coordinated efforts by intermediary organizations. We believe the best candidates for these efforts are organizations—like Carnegie and the New York Academy—with public missions and considerable flexibility and autonomy. Of course, not every city has a science-focused foundation or professional society, which is why we encourage universities to step into this role.

the quality of instruction, demonstrate to the students the future job benefits of a science and math education, and communicate the role of science and math in the world today. Similar initiatives give students and teachers the opportunity to venture out of the classroom and explore the nature of basic research in a professional setting (see Box 4, page 42).[58] High-quality and engaging videos and films can support this objective, while also overcoming geographic, time, and resource constraints that might not allow for in-person interaction.

Improving Graduate Training

Graduate-level scientific training is perhaps the most important segment of the educational pipeline for basic research. A science education that is 16 years in the making can continue on to a career in basic research or can be diverted to some other field, depending on whether or not the college graduate decides to complete graduate training in the sciences. For those choosing a future in basic research, their impact as scientists and engineers depends a great deal on the quality of their graduate training.

Good scientific training is grounded in hands-on exposure to basic research and scientific inquiry. It is essential that graduate students have access to hands-on research projects. **Thus, training of graduate students should be a paramount criterion for universities and faculties in considering their research portfolios, particularly concerning the nature of the research.**

The federal government can help to make graduate student training a higher priority in the research university by increasing the amount of scholarships and training grants available to students. Grant support that goes directly to the student, versus support that comes indirectly from grants for research projects, clearly places the priority on the student's training rather than the needs of any particular research project.

Prolonged time to degree in graduate training is another concern, though admittedly one that is not well understood. To the extent that more time spent attaining the graduate degree reflects a greater complexity of the field of study, there is little to be done and the increased time likely produces a more knowledgeable and productive graduate. But it is undesirable for prolonged time to degree to be caused by higher student-to-faculty ratios, excess time spent on assisting faculty research, or difficulty in securing stable funding.[59] The direct burden and opportunity costs of a longer time to degree are born by today's student, and will also likely have a deterrent effect on those considering graduate training in the future. **We urge research universities to undertake frank and self-critical examinations of their graduate training programs in an effort to expedite the time to degree and reduce the financial and time burden on their graduate students. Again, greater investments in graduate education by science and engineering-related federal agencies can also play an important role in reducing this burden.**

Academic employment is at the core of basic research and will remain so. But an increasing number of PhD scientists and engineers are finding roles, whether by choice or due to a lack of academic alternatives, in the private and other non-academic sectors. Private sector employment of PhD scientists and engineers plays an important role in the dissemination of scientific knowledge. **In order to facilitate the transition from academic training to private sector employment, graduate schools should offer more training programs and mentorships in their curricula that prepare and orient students for employment outside of academe.**

Team-oriented and cross-disciplinary work—an important component of these efforts—need not detract from core disciplinary training. In fact, the Pfizer, Harvard University, and BBN case studies (see Case Studies) all suggest that multi-disciplinary, cross-functional project teams are an increasingly important element of success in many areas of basic research, regardless of whether it is private sector or university research. At the same time, some university research administrators have questioned whether there is adequate grant support for cross-disciplinary and team-oriented research, given the discipline-oriented nature of current grant systems. **CED urges grant-making agencies to support**

more team and cross-disciplinary efforts in research projects.

CED notes that several recent reports address the graduate training issues discussed here, and that reforms in graduate education in the sciences and engineering are underway.[60] Agencies such as the National Science Foundation are responding to the recommendations made by the National Academies and others. Universities also are participating in the renewal of graduate education in the sciences and engineering.

Academic Employment of Young Researchers

Although there is an important role for private sector employment in sustaining the basic research "pipeline," academic employment of scientists and engineers remains central to the health of the basic research enterprise. The trend away from full-time faculty positions at research universities and the increased reliance on post-doctoral, part-time, and temporary employment are not positive signs. They send the wrong signals to today's college and graduate students as they embark on the long and rigorous training necessary for a career in basic research.[61] Hearing horror stories of post-doctoral training that extends well into a young researcher's career, some prospective scientists and engineers are likely to opt out of this career path. **Getting young researchers out of temporary positions and into stable employment should be a priority for all research universities.**

As we discuss earlier in this chapter (see "Problems in the Administration of Federal Grants for University Research," page 36), academic employment also carries with it a large administrative and grant-raising burden. **Research universities and the federal agencies that sponsor universities should be exploring ways to make the academic scientist's work environment more stable and more productive, with less time spent on raising money.**

PRINCIPLES FOR UNIVERSITY RESEARCH IN THE MARKETPLACE

American research universities have always been oriented toward practical concerns, while maintaining excellence in the most theoretical and exploratory corners of science. The transfer of knowledge and new technologies from the university to industry—as embodied in graduates entering the work force, through open dissemination of research results, or through private partnerships, patents, and licensing—is of great economic benefit to the United States. But universities must walk a fine line as they seek to increase the economic value of their basic research, while maintaining a public mission defined by openness and wide dissemination of research findings. This balancing act is made more difficult by the problems researchers face in obtaining public grant support, as indicated earlier in this chapter. CED believes universities, industry, and the federal government should adhere to the following principles as they pursue relationships in basic research.

1. The primary channel of benefit from university research to industrial innovation, and to society at large, is through wide and open dissemination of knowledge in research journals, at conferences, and by the education of graduate students. **New knowledge generated from university research should continue to be openly disseminated. The publication of research findings, upon which future research frequently depends, should be only minimally delayed by patent preparation and other requirements of sponsored research agreements.**

2. Pursuit of patent protection on university inventions, initiation of university-industry partnerships, and licensing of intellectual property for commercial development can stimulate important new research and facilitate and expedite the transfer of new technologies to industry, ultimately benefiting society at large. **Therefore, such partnerships and licensing activities, when structured appropriately (see items 3-5), should be encouraged.**

3. These relationships can create conflicts of interest among the universities, their faculty, and collaborating industrial concerns. **Universities should be strongly encouraged**

to develop, and continually improve, policies and procedures for technology transfer and industry relations, such that the basic educational and research mission of the university is neither diluted nor compromised (see Appendix 2 for two examples of university patent policies).

4. In addition to the need for universities to make research results broadly available, these institutions also have an obligation to devise licensing agreements for technology developed using public funds in a fashion that generates the greatest benefit for society. The guiding principle should be to prevent the university technology transfer system from impeding further research advances, wherever they may occur. **As a general principle, research advances that can be turned into distinct proprietary products are appropriate candidates for exclusive licensing and development. On the other hand, technology that can serve as a tool for many researchers to create new knowledge should be made widely and nonexclusively available under commercially reasonable terms. Industry should recognize and respect these distinctions.**

5. The success of America's basic research enterprise will continue to depend on the use of patented inventions in basic research. In general, basic research will benefit if a patent holder's rights (whether the owner is a company or university) are not enforced in a way that restricts further basic research. Access of all parties to tools for basic research is particularly important in cases where federal funding supported the initial discoveries. **When a research tool is also a research product (as may be the case in areas of biomedical research), the interested parties should work out terms that, first and foremost, do not prevent broad future use of the research tool, and secondly, permit use of the product in the marketplace. Industry and universities should continue to seek avenues which allow the fewest possible restrictions on use of patented inventions for new basic research.**

6. The major research universities have developed policies that honor the public responsibilities of their research mission. These policies are particularly important in maintaining the central purpose, value and morale of the faculty who are the lifeblood of the university. In particular, it is important that the interests of industry not influence critical decisions of the university regarding hiring, compensation and promotion. **The continued strength of basic research in America depends on the ability of faculty members to devote their energies to, and be evaluated by, their quality and contributions as basic researchers and their success in educating new scientists. Commercial successes are secondary to these missions.**

7. **Finally, private sector funding of university research or research supported through licensing fees should not be viewed by universities or the federal government as substitutes for federal funding.** The objectives and goals of private firms are different from public missions and should not be allowed to define the character of university research in general. Ultimately, the only way to maintain basic research in the university as it has been characterized over the past half-century is through predominately public funding.

INTERNATIONAL CHALLENGES AND OPPORTUNITIES FOR AMERICAN BASIC RESEARCH

Maintaining a Commitment to Basic Research in a Global Economy

Basic research activities around the world are increasing as other countries step up the pace of their research investments. At the same time, the new knowledge derived from basic research moves more easily across national borders than ever before, thanks to the dramatic advances in information technology. Transfer of information is also facilitated by the steady pace of economic globalization.

These trends have led some to question the viability of our national basic research enterprise in an increasingly international economy. In fact, some argue that because the products of our basic research now move freely and quickly to other countries, or to foreign subsidiaries of U.S. firms, U.S. taxpayers should not pay for it. They argue that the United States should take better advantage of other nations' basic research, or should attempt to limit foreign access to new American knowledge. **CED strongly believes that arguments for reducing or restricting access to the outcomes of U.S. efforts in basic research, based on fears of foreign appropriation of American discoveries, are misguided and could undermine the central role that the federal government plays in funding American basic research.**

We readily acknowledge that other countries benefit from our basic research. In some cases, U.S. firms have been slow to capitalize on technological breakthroughs. This reflects poorly on U.S. technological development and is not a failing of the basic research enterprise.

The foreign benefit from American basic research need not be our loss. Performing initial basic research should position us to exploit benefits faster than can the followers and the "freeloaders." If we reduce our efforts in basic research, we will lose this "first mover" advantage. Also, by promoting an open two-way environment for new knowledge, we are able to share in other countries' basic research findings, even to the point of exploiting those findings more quickly than firms in those countries.

Finally, a robust basic research enterprise in American universities keeps our high-tech firms on-shore, while also attracting foreign firms to invest within our borders. The scientists and engineers at our research universities are an enormous international strategic advantage.

In sum, more basic research activity around the globe will present tremendous opportunities for scientific progress, with large payoffs for all nations. Nationalistic attitudes and policies are counterproductive to this progress and have no place in a productive global basic research enterprise. **It is critical, then, that the United States take a leadership position in ensuring the free flow of fundamental knowledge and basic research findings globally.**

Intellectual Property Worldwide

Although CED does not view the international spillover of non-proprietary knowledge derived from basic research as a negative, we are concerned about the impact of weak intellectual property laws in other countries on innovation in the United States and globally. U.S. patent laws play a very large role in stimulating innovative activities in this country by protecting a company's rights to discoveries and innovations that are proprietary in nature; in this way, the company is able to capture the returns on its investment. In an increasingly global environment and one in which a growing number of countries are investing in research, it is in the interest of all countries to play by the same rules regarding intellectual property. The pirating of intellectual property that occurs in other countries ultimately hurts all levels of innovative activity, from basic research to commercial development.

Pursuing International Collaboration

Some areas of science have become too expensive and too risky to be supported solely by a single country. Because of their ultimate potential benefit, such projects deserve international cooperation— in funding, institutional collaboration, and sharing of scientists and results. Mistrust between countries in such projects ignores the reality of global science today. A great deal of scientific information already flows freely across national borders through publications, research conferences, and through the Internet and other forms of information technology. By cooperating in large-scale projects, the United States and other countries extend globalization to projects that are not sustainable at a national level. **CED believes the United States must pursue international cooperation in "big science," in order to optimize advances in science and technology.**

Supporting Foreign Scientists and Engineers in the United States

In an increasingly global scientific community, American training of foreign scientists is another welcome form of international research cooperation. The participation of foreigners in American universities and in American science and engineering programs benefits the U.S. research enterprise and the economy in general.[62] Foreign students contribute to our basic research through participation in university research. Given the capacity of the American research university system, it is unlikely that these students are significantly "crowding out" high-potential American students. Many foreign graduates will choose to remain in the United States as professional scientists and engineers (about 40 percent in recent years).[63]

The direct participation of foreign students and professionals in American basic research will likely decline in the future, as foreign economies become more sophisticated. How the United States reacts to these trends is critical to the future of our own basic research enterprise. CED believes the United States should continue to make reasonable efforts to attract foreign scientists. **Our immigration policies should be further liberalized to allow foreign scientists and engineers to live and work in the United States through permanent visas. Also, immigration policies should encourage foreign scientists and engineers to visit the United States on a temporary basis as consultants or participants in research collaborations.**

CONCLUSION

We are in the midst of a remarkable period of discovery and innovation. Ask those engaged in the discovery process what they think about the future of their particular discipline and the answer is likely to be strikingly positive, with postulations about breakthroughs that are unfathomable to us today. Add to this optimism the impact of the current economic boom, which is making the most of product innovations and bringing new technologies to market at a dizzying pace. Together, these trends create an atmosphere of almost boundless enthusiasm about the future.

Raising a cautionary note about the future of the basic research enterprise in this environment, then, is no easy task. Certainly, we do not foresee calamity on the horizon. The United States will continue to see pay-offs from its basic research investments, as it has throughout this century.

Yet, today's emerging problems, left unchecked, become a potent threat to tomorrow's research enterprise. In this sense, the reforms we have recommended in this report—shoring up the system of competitive peer review, maintaining adequate resources, and correcting deficiencies in the educational and employment pipeline, to name a few—are more than just fine-tuning. Problems in each of these areas have the potential to erode the quality and quantity of output we have come to expect from American basic research.

Dealing with these challenges requires resolve. Certainly, if reforming the national laboratories is politically difficult, K-12 educational reform is even more so. The key for policymakers, and for the citizens they represent, is to keep their focus on the potential for the future. The pay-offs from a basic research enterprise that is working at its full capacity are tremendous, and far too great to forgo for lack of political will.

OVERVIEW OF RESOURCES FOR BASIC RESEARCH

An important constant in the success of American basic research has been the substantial financial support it has received throughout most of the post-World War II era. In terms of dollars spent and the number of scientists employed in research activity (see Appendix Box 1, "Research Dollars Versus Other Inputs"), both total R&D and basic research have expanded over the past fifty years.

However, in recent years, as post-Cold War priorities and missions are being sorted out, growth in basic research spending relative to GDP has been weaker. As Appendix Figure 1, page 49 indicates, federal basic research is about the same today as a proportion of GDP as it was in 1970. While industrial support for basic research has risen slightly in the last decade, it remains well below federal support. Moreover, the rate of increase in industrial support for basic research has slowed considerably during the 1990's.

Basic research is not a large share of total R&D for industry or government (see "Why Does Government Support Basic Research?," page 12). Industry spends considerably more on R&D overall but much less than the federal government on basic research (see Appendix Figure 2, page 50). Indeed, the large amount of industry development spending overshadows all other categories of research spending both in industry and government. Of the nearly $63 bil-

APPENDIX BOX 1

RESEARCH DOLLARS VERSUS OTHER INPUTS

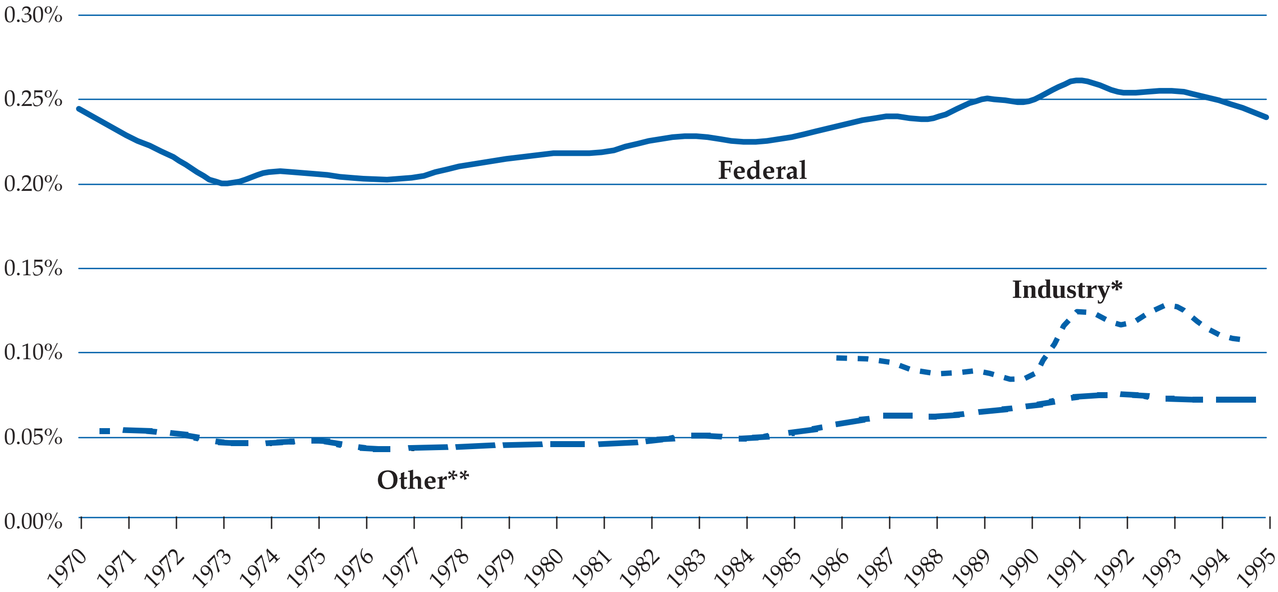
Focusing solely on the financial resources devoted to basic research overlooks other important factors in measuring research activity, namely the amount of labor and capital inputs devoted to science. While research dollars are frequently used as a proxy for these inputs and for research activity in general, it is important to keep in mind that these dollars purchase the services of scientists and engineers, as well as the equipment they employ. Does an increase or decrease in dollars spent on research activities represent a one-for-one movement in the number of researchers or amount of research equipment employed? Or has the cost of these inputs—that is, the real cost of doing research—changed in a way that our standard cost measures fail to capture?

In fact, the amount of research inputs employed appears to have kept pace with dollars spent on R&D. Over the same period (1981-1993) that total R&D spending increased about 40 percent in inflation-adjusted dollars, the number of scientists and engineers engaged in research activities also increased about 40 percent (see Appendix Figure 3, page 51).

At the same time, attempts to account for the cost of research at a macroeconomic level suggest that some types of research have become more expensive relative to other forms of economic activity.[1] Specifically, the cost of university research (reflecting personnel, equipment, and facilities) rose 10 percent faster than prices in the economy in general in 1992. However, the cost of industrial research grew at a slightly slower rate than economy-wide prices, and non-manufacturing R&D costs grew at an even slower rate.

Appendix Figure 1

Federal, Industry, and Other Funds for Basic Research as a Percentage of GDP



*Industry data prior to 1986 are not comparable to post-1989 data.
**Includes universities' and colleges' own funds, state/local government funds to universities and colleges, and funds from other non-profits.
SOURCE: National Science Board, *Science & Engineering Indicators—1996,* (Washington, DC: U.S. Government Printing Office, 1996), Appendix Tables 4-1 and 4-5.

lion that government spends on R&D annually, $17.7 billion goes to basic research. And of the $133 billion that industry spends on R&D, a much smaller share, just $8 billion, goes to basic research.

The Central Role of Federal Government in Funding Basic Research

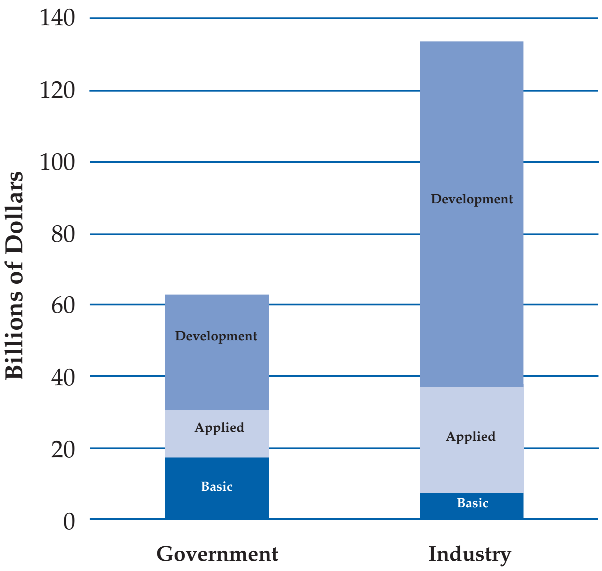
The most important source of funds for basic research since World War II has been the federal government. Through most of the post-World War II period, growth in federal support for basic research was substantial and quite stable. However, relative to growth in the economy, federal support for basic research has remained virtually flat in recent years (see Appendix Figure 1) and long-term federal budgetary and demographic trends suggest an even less favorable outlook for the future.

As a relative priority in the federal budget, basic research expenditures are well below the peak achieved during the height of the space program in the mid-1960's (see Appendix Figure 4, page 52). However, basic research spending has maintained a level of just over one percent of federal outlays in the past decade, a period when total federal R&D slipped as a budget priority. The relative importance of basic research, and of R&D in general, has been greatly overshadowed by rapid growth in outlays for entitlement programs and interest on the debt, which have crowded out discretionary spending in general, including research spending (see Appendix Figure 5, page 52).

It is the long-term funding picture, however, that is most striking. The retirement of the baby boomers will place unprecedented demand on the federal budget, primarily for Social Security and Medicare.[2] *Under current policies, entitlement and interest outlays are projected to account for 70 percent of the federal budget by 2002, compared to just one-third of the budget during the peak years*

Appendix Figure 2

Basic, Applied, and Development Research Spending by Government and Industry for 1997



NOTE: Data are preliminary for this year.
SOURCE: NSF, Science Resources Studies Division (data available at *www.nsf.gov*).

for research spending (the mid-1960's). Under such a scenario, basic research would almost certainly see a substantial decline in funding.

Again, a majority of federal R&D funds is devoted to development work, which is primarily carried out by private companies (see Appendix Figure 6, page 53). In contrast, the smaller portion of federal R&D devoted to basic research is directed primarily to universities, with a very small amount directed to industry and non-profit institutions. As Appendix Figure 6 illustrates, the amount of federal basic research performed directly by federal agencies (in labs like the National Institutes of Health or the Department of Energy's "national labs") is small relative to the total federal R&D budget.

Most federally-sponsored basic research supports agency missions. In this sense, basic research does not generally conform to its stereotype, which is that it is untargeted and devoid of any defineable goal beyond the advancement of knowledge. In fact, basic research supported by the Departments of Defense and Energy, and through the National Institutes of Health, has very strong goals in specific mission areas. Only 15 percent is funded through the National Science Foundation, which provides support for basic research outside of the agency missions and is based primarily on scientific and engineering disciplines.

Federal support for basic research is by no means uniform across scientific disciplines. As Appendix Figure 7, page 53 illustrates, federal basic research outlays in the life sciences far surpass those in other disciplines. In fact, funding for the life sciences is on a par with all other disciplines combined. This disparity in funding levels appears to reflect a strong public priority placed on health-related research, particularly in high profile areas like cancer and AIDS research. However, as many prominent scientists within and outside of health research have noted, breakthroughs in medical science often rely on research conducted in disciplines far afield from the life sciences, including mathematics, physics, computer science, and the social sciences.

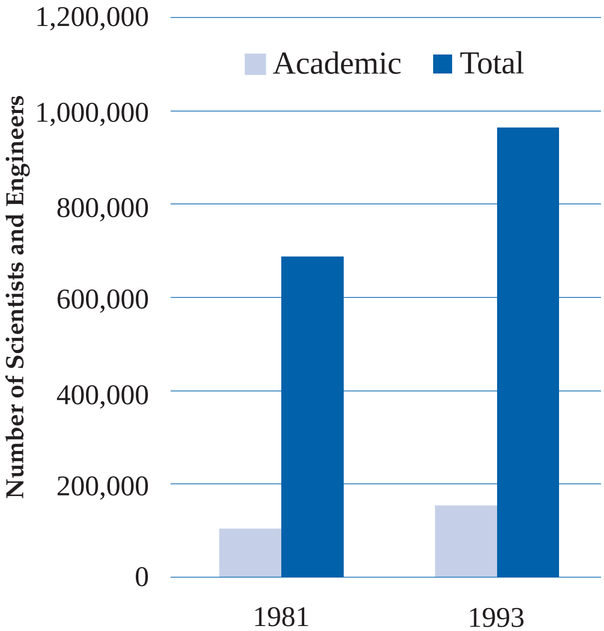
The importance of multi-disciplinary research is illustrated by the experience of the private sector. Several of the case studies presented in the next section demonstrate that successful basic research often does not mean narrow basic research. Merck's efforts in AIDS research have been multi-dimensional by necessity, given the uncertainties of the basic research endeavor. The Procter & Gamble case study also illustrates the necessarily wide, cross-disciplinary net that must be cast to achieve progress in particular areas of innovation: for Procter & Gamble, this meant supporting biological research, far afield from the company's core basic research activities in chemistry.

Overview of Resources for University Research

Public and private funding for university research has increased dramatically over the past four decades, from just under $3 billion in 1959 to over $22 billion in 1996 (expressed in con-

Appendix Figure 3

Academic Employment and Total Employment of Scientists and Engineers Engaged in R&D in the United States



NOTE: Data for academic employment represent doctoral scientists and engineers. Other data represent all scientists and engineers.
SOURCE: National Science Board, *Science & Engineering Indicators—1996* (Washington, DC: U.S. Government Printing Office, 1996), Appendix Tables 3-19 and 5-19.

stant 1996 dollars; see Appendix Figure 8, page 54). As Appendix Figure 8 indicates, this growth has been driven largely by increasing federal support, although industry and institutional support have also increased significantly in recent years. Industry's share of support has grown from 3 percent in 1965 to 7 percent in 1996 (see Appendix Figure 9, page 54).

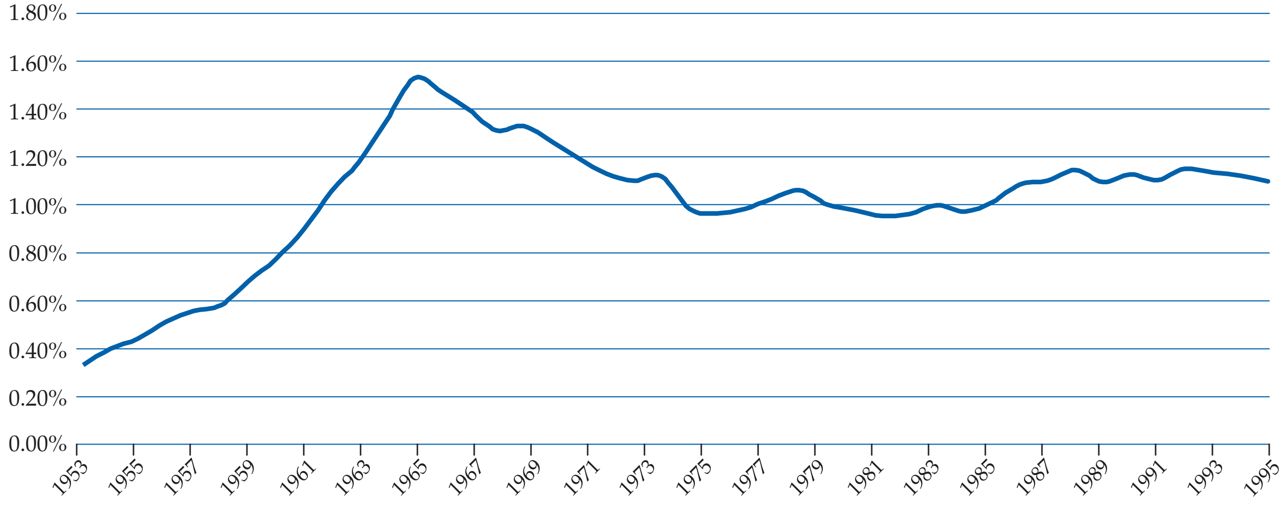
Reflecting the priorities of the federal government, and society at large, university health research ("life sciences") has been by far the largest recipient of federal and non-federal resources (see Appendix Figure 10, page 55). All fields have seen some increase in funding between 1989 and 1996. At the low end, mathematical sciences received average annual increases of 1.5 percent (after inflation) during this period. At the high end, the social sciences received annual increases averaging 7 percent. The growth rate for life sciences research was 3 percent; this increase in resources greatly exceeds that for other disciplines because it began from a much higher base level.

Although National Institutes of Health funding dominates university research (see "HHS" category in Appendix Figure 11, page 56), other agencies are more important to disciplines outside of the life sciences (see Appendix Figure 12, page 56). For example, research in the computer sciences relies on Department of Defense dollars for 58 percent of its federal funding. The National Science Foundation is the largest funding agency for the physical, mathematical, and environmental sciences.

Another important, though indirect, source of federal funding for university research comes from medical services revenues.[3] University hospitals have become important providers of medical care, particularly to Medicare and Medicaid recipients. As a result, these two programs have indirectly funded both health research in the university hospital and research elsewhere in the university through cross-subsidization. With the likelihood of more stringent cost controls in Medicare and Medicaid, this indirect source of funding for university research is expected to decline.

Appendix Figure 4

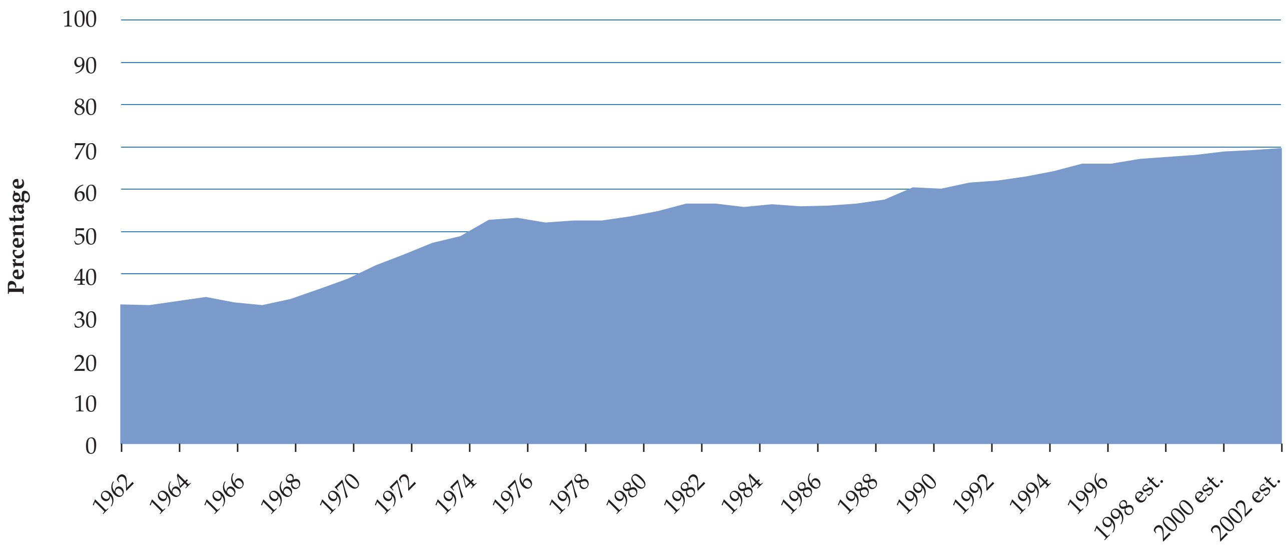
Federal Basic Research Spending as a Percent of Total Federal Outlays



SOURCE: Science Resource Studies Division, NSF (data available at www.nsf.gov); Budget of the United States Government, FY 1998.

Appendix Figure 5

Entitlements and Net Interest on the Debt as a Percentage of Total Federal Outlays

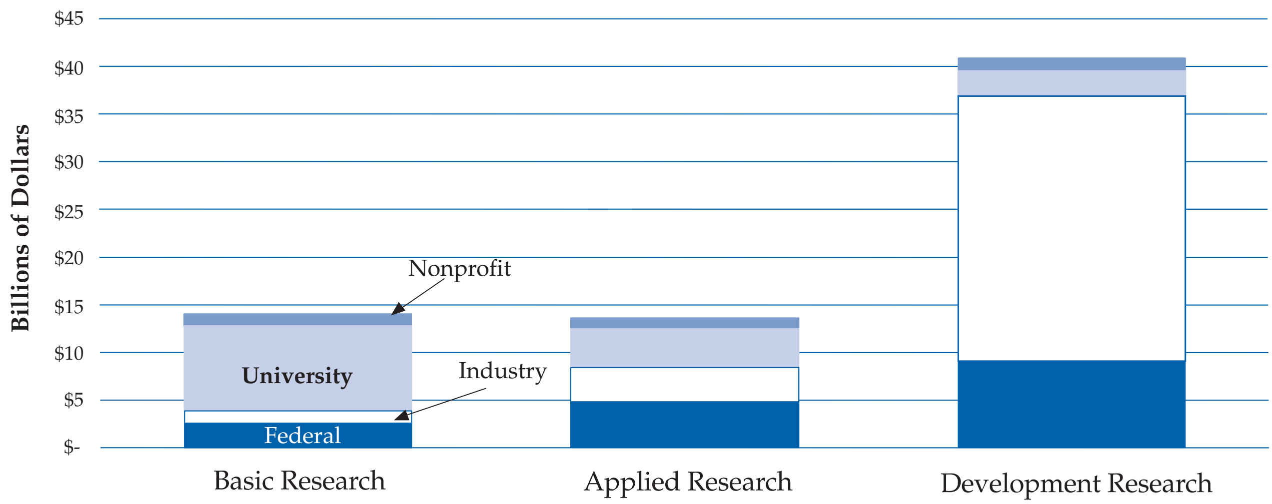


SOURCE: *Budget of the U.S. Government, FY 1999*, historical tables, (Washington, D.C.: U.S. Government Printing Office).

Appendix Figure 6

Federal R&D by Character of Work and Performer

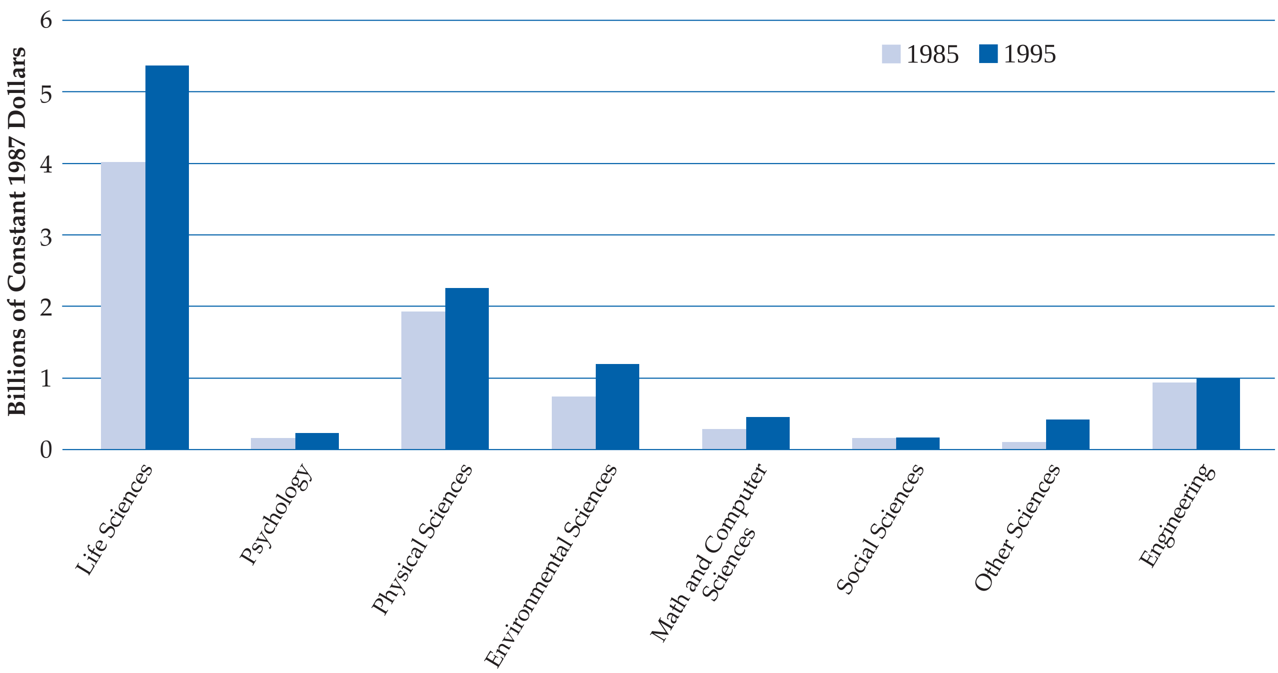
1995



SOURCE: National Science Board, *Science & Engineering Indicators—1996*, (Washington, DC: U.S. Government Printing Office, 1996), Appendix Table 4-18.

Appendix Figure 7

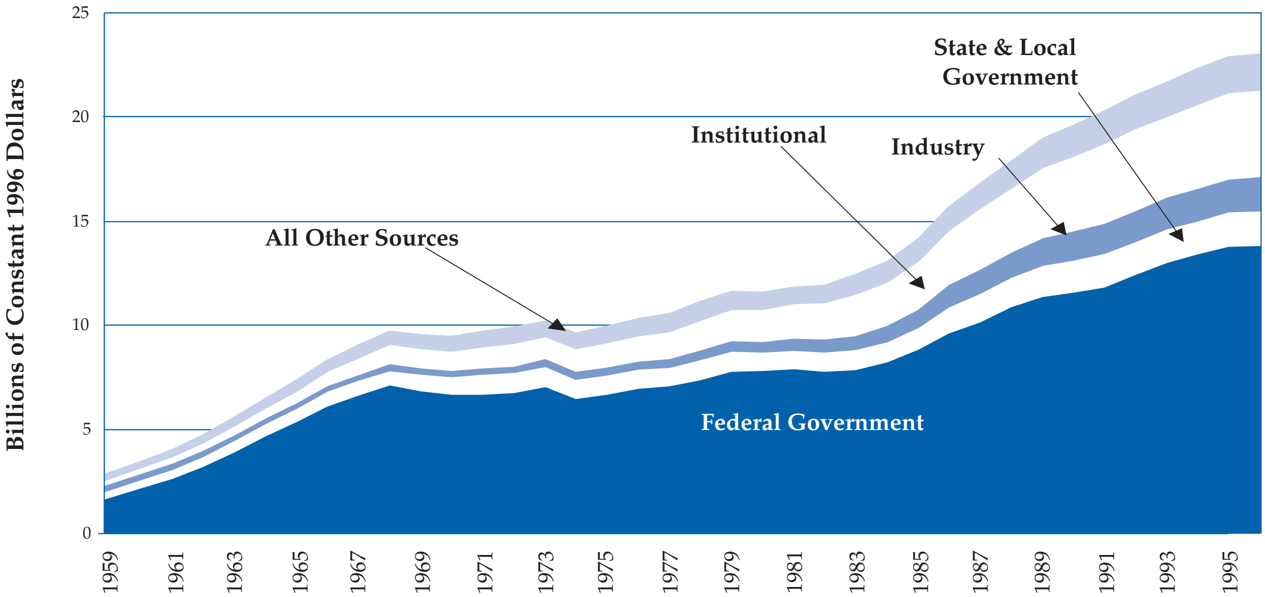
Federal Obligations for Basic Research by Field



SOURCES: Science Resources Division, National Science Foundation, *Federal Funds for Research and Development, Detailed Historical Tables: Fiscal Years 1956-95*, NSF 95-319 (Bethesda, Md.: Quantum Research Corp., 1995), and SRS, *Federal Funds for Research and Development: Fiscal Years 1993, 1994, and 1995* (Arlington, Va.: NSF, forthcoming).

Appendix Figure 8

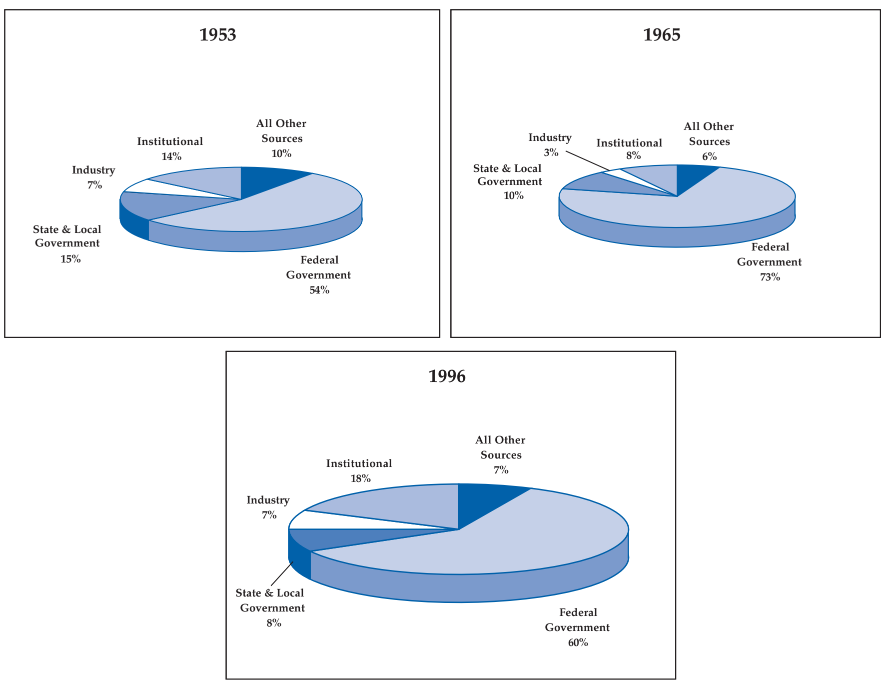
Research Expenditures at Universities and Colleges, by Souces of Funds



SOURCE: National Science Foundation, Science Resources Studies Division, *Survey of Research and Development Expenditures at Universities and Colleges,* Fiscal Year 1996.

Appendix Figure 9

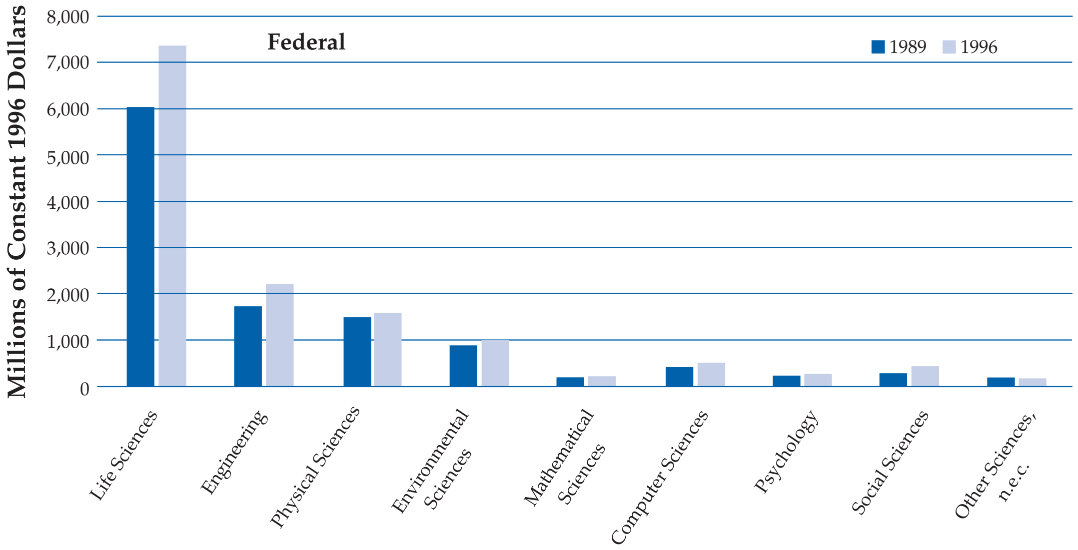
Sources of Funding for University Research

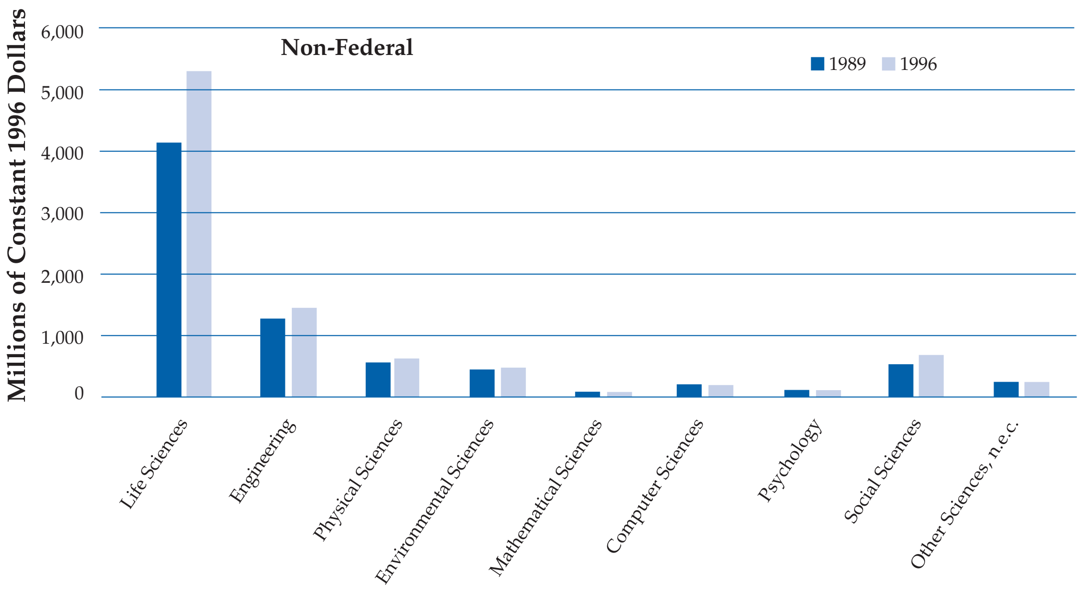


SOURCE: National Science Foundation, Science Resources Studies Division, *Survey of Research and Development Expenditures at Universities and Colleges,* Fiscal Year 1996.

Appendix Figure 10

Federal and Non-Federal Funding by Research Field at Universities & Colleges

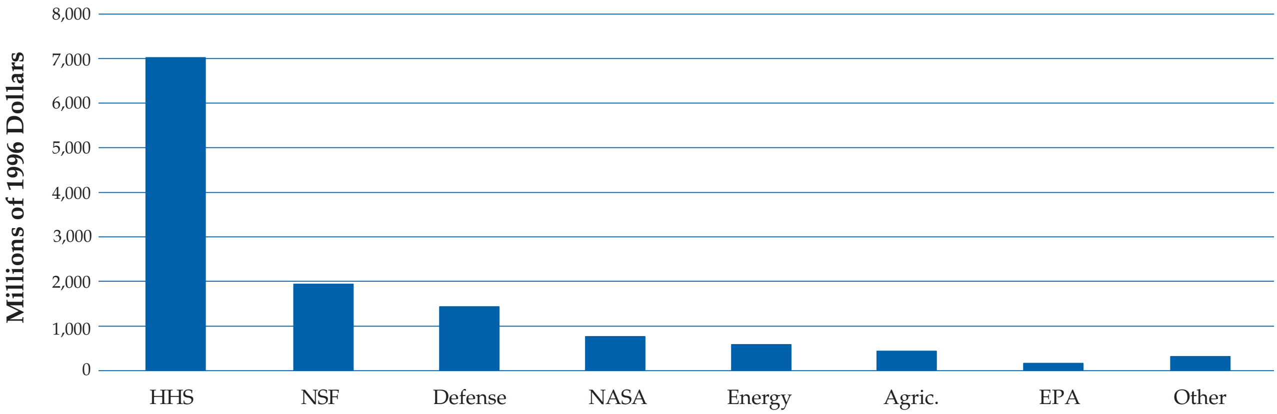




SOURCE: National Science Foundation, Science Resources Studies Division, *Survey of Research and Development Expenditures at Universities and Colleges,* Fiscal Year 1996.

Appendix Figure 11

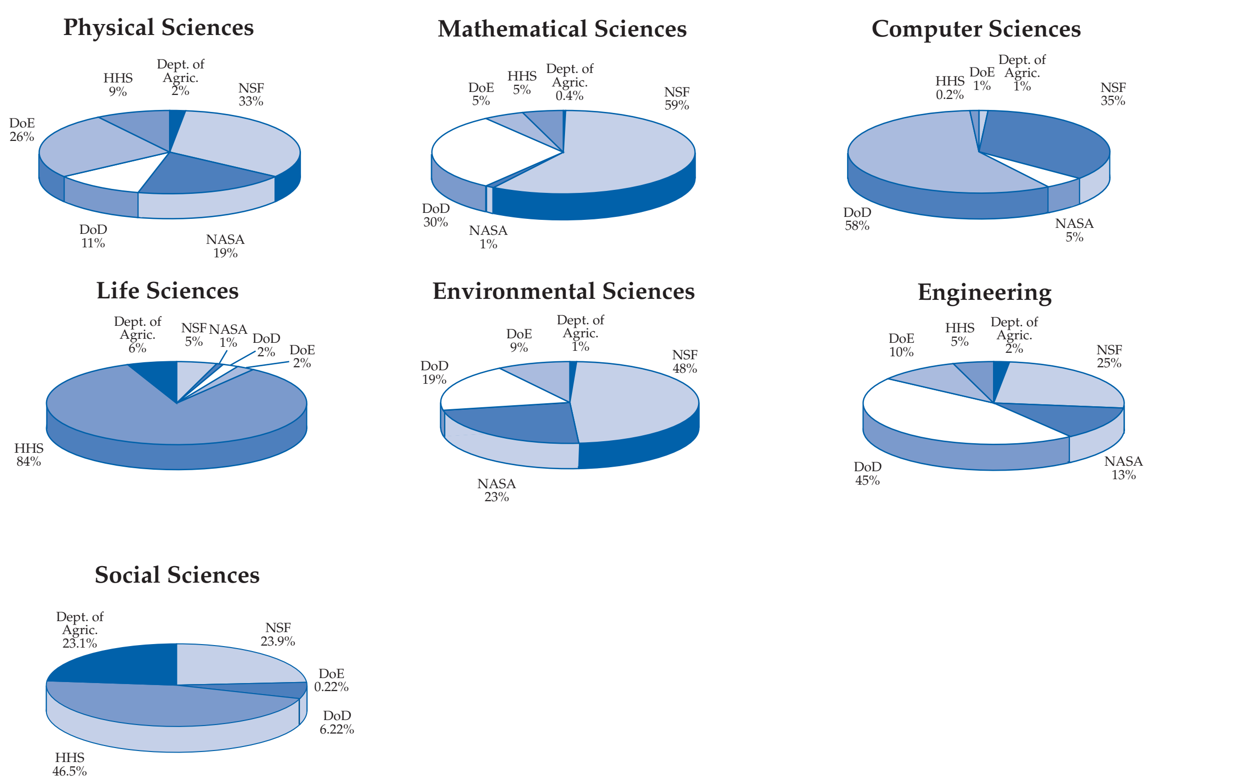
Agency Support for Conduct of Research at Universities and Colleges, FY 1996



SOURCE: *AAAS Report XXII: Research and Development FY 1998,* Intersociety Working Group, (AAAS: Washington, DC), Table I-9.

Appendix Figure 12

Federal Academic Research Obligations, by Major Federal Agencies, for Various Sciences. 1993-95 Average



SOURCE: National Science Board, *Science & Engineering Indicators—1996,* (Washington, DC: U.S. Government Printing Office, 1996), Table 5-11.

APPENDIX 2

UNIVERSITY PATENTING GUIDELINES

In this appendix, we present two examples of university patent policies, from the University of California system and Cornell University. Both affirm the primary intent of research at their universities — the pursuit of knowledge — while recognizing the potential for by-products that have commercial potential and are suitable for patenting.

These two policies differ, as do others, on the distribution formulas for licensing revenues. Although the specific percentages for distribution vary, formulas are generally structured to reward the researcher and the researcher's department or laboratory with some percentage of these revenues. In this way, some of the revenues resulting from research are directed back to research activities.

A common feature of these policies is the stated requirement of researchers to disclose potentially-patentable inventions to the university. The university then decides whether or not to pursue a patent on the invention. Some policies state the perogative of the researcher to place research findings directly in the public domain, effectively forfeiting the university's ability to assert intellectual property rights. However, there is tremendous pressure as well as a financial incentive for researchers to first disclose their findings to the university. Universities emphasize that this disclosure and the patent application process need not interfere with the publication of research findings, but filing for the patent must occur before publication or other forms of public disclosure.

UNIVERSITY OF CALIFORNIA PATENT POLICY

(Reprinted with the permission of the University of California)

I. PREAMBLE

It is the intent of the President of the University of California, in administering intellectual property rights for the public benefit, to encourage and assist members of the faculty, staff, and others associated with the University in the use of the patent system with respect to their discoveries and inventions in a manner that is equitable to all parties involved.

The University recognizes the need for and desirability of encouraging the broad utilization of the results of University research, not only by scholars but also in practical application for the general public benefit, and acknowledges the importance of the patent system in bringing innovative research findings to practical application.

Within the University, innovative research findings often give rise to patentable inventions as fortuitous by-products, even though the research was conducted for the primary purpose of gaining new knowledge.

The following University of California Patent Policy is adopted to encourage the practical application of University research for the broad public benefit; to appraise and determine relative rights and equities of all parties concerned; to facilitate patent applications, licensing, and the equitable distribution of royalties, if any; to assist in obtaining funds for research; to provide for the use of invention-related income for the further support of research and education; and to provide a uniform procedure in patent matters when the University has a right or equity.

II. STATEMENT OF POLICY

A. An agreement to assign inventions and patents to the University, except those resulting from permissible consulting activities without use of University facilities, shall be mandatory for all employees, for persons not employed by the University but who use University research facilities, and for those who receive gift, grant, or contract funds through the University. Such an agreement may be in the form of an acknowledgment of obligation to assign. Exemptions from such agreements to assign may be authorized in those circumstances when the mission of the University is better served by such action, provided that overriding obligations to other parties are met and such exemptions are not inconsistent with other University policies.

B. Those individuals who have so agreed to assign inventions and patents shall promptly report and fully disclose the conception and/or reduction to practice of potentially patentable inventions to the Office of Technology Transfer or authorized licensing office. They shall execute such declarations, assignments, or other documents as may be necessary in the course of invention evaluation, patent prosecution, or protection of patent or analogous property rights, to assure that title in such inventions shall be held by the University or by such other parties designated by the University as may be appropriate under the circumstances. Such circumstances would include, but not be limited to, those situations when there are overriding patent obligations of the University arising from gifts, grants, contracts, or other agreements with outside organizations. In the absence of overriding obligations to outside sponsors of research, the University may release patent rights to the inventor in those circumstances when:

(1) the University elects not to file a patent application and the inventor is prepared to do so, or

(2) the equity of the situation clearly indicates such release should be given, provided in either case that no further research or development to develop that invention will be conducted involving University support or facilities, and provided further that a shop right is granted to the University.

C. Subject to restrictions arising from overriding obligations of the University pursuant to gifts, grants, contracts, or other agreements with outside organizations, the University agrees, following said assignment of inventions and patent rights, to pay annually to the named inventor(s), or to the inventor(s)' heirs, successors, or assigns, 35% of the net royalties and fees per invention received by the University. An additional 15% of net royalties and fees per invention shall be allocated for research-related purposes on the inventor's campus or Laboratory. Net royalties are defined as gross royalties and fees, less the costs of patenting, protecting, and preserving patent and related property rights, maintaining patents, the licensing of patent and related property rights, and such other costs, taxes, or reimbursements as may be necessary or required by law. Inventor shares paid to University employees pursuant to this paragraph represent an employee benefit.

When there are two or more inventors, each inventor shall share equally in the inventor's share of royalties, unless all inventors previously have agreed in writing to a different distribution of such share.

Distribution of the inventor's share of royalties shall be made annually in November from the amount received during the previous fiscal year ending June 30th, except as provided for in Section II.D. below. In the event of any litigation, actual or imminent, or any other action to protect patent rights, the University may withhold distribution and impound royalties until resolution of the matter.

D. The DOE Laboratories may establish separate royalty distribution formulas, subject to approval by the President. Distribution of the inventor's share of DOE Laboratory royalties shall be made annually in February from the amount received during the previous fiscal year ending September 30th. All other elements of this policy shall continue to apply.

E. Equity received by the University in licensing transactions, whether in the form of stock or any other instrument conveying ownership interest in a corporation, shall be distributed in accordance with the Policy on Accepting Equity When Licensing University Technology.

F. In the disposition of any net income accruing to the University from patents, first consideration shall be given to the support of research.

III. PATENT RESPONSIBILITIES AND ADMINISTRATION

A. Pursuant to Regents' Standing Order 100.4(mm), the President has responsibility for all matters relating to patents in which the University of California is in any way concerned. This policy is an exercise of that responsibility, and the President may make changes to any part of this policy from time to time, including the percentage of net royalties paid to inventors.

B. The President is advised on such matters by the Technology Transfer Advisory Committee (TTAC), which is chaired by the Senior Vice President—Business and Finance. The membership of TTAC includes the Provost and Senior Vice President—Academic Affairs, the Director of the Office of Technology Transfer, and representatives from the campuses, DOE Laboratories, Academic Senate, the Division of Agriculture and Natural Resources and the Office of the General Counsel. TTAC is responsible for:

1. reviewing and proposing University policy on intellectual property matters including patents, copyrights, trademarks, and tangible research products;
2. reviewing the administration of intellectual property operations to ensure consistent application of policy and effective progress toward program objectives; and
3. advising the President on related matters as requested.

C. The Senior Vice President—Business and Finance is responsible for implementation of this Policy, including the following:

1. Evaluating inventions and discoveries for patentability, as well as scientific merit and practical application, and requesting the filing and prosecution of patent applications.
2. Evaluating the patent or analogous property rights or equities held by the University in an invention, and negotiating agreements with cooperating organizations, if any, with respect to such rights or equities.
3. Negotiating licenses and license option agreements with other parties concerning patent and or analogous property rights held by the University.
4. Directing and arranging for the collection and appropriate distribution of royalties and fees.
5. Assisting University officers in negotiating agreements with cooperating organizations concerning prospective rights to patentable inventions or discoveries made as a result of research carried out under gifts, grants, contracts, or other agreements to be funded in whole or in part by such cooperating organizations, and negotiating with Federal agencies regarding the disposition of patent rights.
6. Approving exemptions from the agreement to assign inventions and patents to the University as required by Section II.A. above.
7. Approving exceptions to University policy on intellectual property matters including patents, copyrights, trademarks, and tangible research products.

CORNELL UNIVERSITY PATENT POLICY

(Reprinted with the permission of Cornell University)

The following policy was approved by the Executive Committee of the Cornell University Board of Trustees on May 26, 1995 to be effective July 1, 1995.

A. General Statement

The Board of Trustees of Cornell University, recognizing that inventions and discoveries of commercial importance may be the natural outgrowth of research conducted by faculty, staff and students, and desiring to secure both public benefit from the applications of such research and enhancement of the University's capacity for such research, has established the following Patent Policy.

1. Cornell University's primary obligation in conducting research is the pursuit of knowledge for the benefit and use of society.
2. The University depends upon financial support from governmental agencies, private foundations, corporations, operated for profit and others for the basic and applied research endeavors of the faculty and staff. As University Research enjoys substantial public support it is incumbent upon the Univer-sity to seek assurance that any resultant patent right be administered consistent with the public interest.
3. Inasmuch as new ideas and discoveries of commercial interest are often a consequence of University Research, and inasmuch as patent protection can often enhance the reduction to a public usefulness of inventions which result from University Research, Cornell, as a general policy, will seek patent protection for those ideas and discoveries which arise out of the research activities of its faculty and staff where it appears necessary or desirable to do so.
4. It is the judgment of the University that the reduction to a public usefulness of inventions and discoveries resulting from University Research, the publication and availability for educational purposes of the fruits of such research, and the achievement of a fair and equitable distribution of royalties which acknowledges both the contribution of the inventor, and the University can best be assured by operation of a uniform Patent Policy which provides for University ownership of inventions.

B. University Research

University Research shall be defined, for the purpose of this Patent Policy, to include all research conducted in the course of an inventor's employment with the University (including but not limited to the performance of a grant contract or award made to the University by an extramural agency) or with the use of University Resources.

C. Disclosure of Inventions

Inventions conceived or first reduced to practice in furtherance of the University Research of faculty or staff shall be promptly disclosed in writing to the Cornell Research Foundation.

D. Ownership of Inventions

1. All patentable inventions conceived or first reduced to practice by faculty and staff of Cornell University in the conduct of University Research shall belong to the University. The inventor shall cooperate and assist the University in all phases of the patent application process and shall assign such applications or any patents resulting therefrom to Cornell Research Foundation, Inc.
2. Patentable inventions made by individuals on their own time and with-

out the use of University resources shall belong to the individual inventor.

3. In cases in which the University has an ownership interest in an invention pursuant to paragraph D(1) and either does not file a patent application within one year, or fails to make a positive determination regarding pursuit of a patent within a period of six months from the date of disclosure, all of the University's rights shall be reassigned to the inventor upon request, subject only to such external sponsor restrictions as may apply.

E. Royalty Distribution

1. In the case of a patent owned by the University pursuant to paragraph D(1) above, and in recognition of the efforts and contributions of the inventor, total net royalty income shall be distributed as follows:

50% of the first $100,000.00
25% of net royalty income in excess of $100,000.00

Joint inventors shall share the percentage of net royalty income allocated to the Inventor. Any person hired or retained for the purpose of producing an invention shall not be entitled to a distribution of net royalty income with respect to that invention.

2. Cornell Research Foundation shall receive 35% of the net royalty income to provide operating funds to cover the cost of service provided to the University with regard to intellectual property matters and particularly to cover the costs associated with patenting and marketing inventions where royalty income or other cost recovery has not been achieved. Cornell Research Foundation's prior deficits shall be retired using this portion. The percentage of net royalty income to Cornell Research Foundation shall be evaluated annually by the Board of Directors of the Foundation and reduced when deficits have been eliminated. The Cornell Research Foundation Board of Directors shall be responsible to adjust the percentage received by Cornell Research Foundation with a two year lead time following the elimination of the Foundation's deficits.

3. Net royalty income shall mean gross royalties received by the University less directly assignable expenses resulting from patenting and licensing the particular invention .

4. The remainder of the net royalty income shall be divided (a) 60% to the inventor's research budget, subunit and University unit in a manner to be mutually agreed upon and (b) 40% to the University for general research support.

5. For any year in which the net royalty income distributed to a unit of the University for a particular invention emanating from that unit shall exceed 20% of the annual sponsored research as determined by the Office of Sponsored Programs for that unit in that year, the excess received from Cornell Research Foundation shall be retained as endowment for the unit. The Dean or Director of the unit may similarly require that corresponding royalty income to a subunit exceeding 20% of the total sponsored research of the inventor's appropriate subunit be retained as endowment for the benefit of the subunit. In the event that a lump sum royalty payment contributes to the generation of excess royalty income in a given year as defined above, Cornell Research Foundation may distribute such lump sum payment to the unit or subunit over a three year period together with accumulated interest. In such case, the provisions of this paragraph shall apply to the resulting annual distributions.

6. In the case of an invention unresolvable dispute over distributions in 4 (a), net royalty income distributed under 4 (a) shall be allocated and made on an equi-

table basis as determined by the Vice President for Research.

F. Licensing Policy

It is the general policy of the University to encourage the development and marketing of inventions resulting from University research so as to reach a public usefulness and benefit. It is recognized that furtherance of such a policy may require various forms of agreements including the granting of exclusive licenses.

Cornell Research Foundation may, in appropriate circumstances with due consideration to the prospective licensee and when consistent with law applicable to federally supported research, license an existing patent or invention on an exclusive basis for a reasonable period up to the full term of the patent, provided that such an exclusive license shall contain provisions to promote the likelihood that the invention provides a public benefit, including but not limited to a requirement of diligence and march-in rights where the licensee does not adequately perform.

G. Waiver Requests

Waiver of any provisions of the Patent Policy shall be granted only in extraordinary and compelling circumstances and pursuant to the procedure described below.

A request for waiver of any of the provisions of this Patent Policy shall be submitted to the President of Cornell Research Foundation & the Vice President for Research for transmittal to the Patent Advisory Committee. Such request shall include an identification of the provision or provisions of the Policy requested to be waived, and a full explanation of the reasons for the waiver including, but not limited to, the manner in which the waiver is consistent with the educational purposes of the University and the public interest.

The University recognized that certain sponsors may wish to impose as a condition of the award of contract or grant funds special provisions which are at variance with this Patent Policy. Under such circumstances, the University may entertain such proposals as requests for waiver under this paragraph subject to the additional condition that all faculty or staff members engaged in research to be supported by the proposed grant or contact containing such provisions shall acknowledge and accept those specific provisions.

The Patent Advisory Committee shall review each request for waiver and submit a report of its findings and recommendation to the Vice President for Research whose decision shall be final. Each action under this section shall considered on its own merits in light of all of the facts surrounding the particular request and shall have no implication for consideration of subsequent requests. Waiver of provisions relating to distribution of net royalty income shall, in addition, require the approval of the Dean or Director of the unit from which the invention emanated.

H. Deferral

This statement of Patent Policy shall not prevent participation under research agreements with, or the conduct of research for, governmental agencies (local, state or federal) subject to laws or regulations which require a different disposition of patent rights than herein provided, or impose other provisions which are in addition to, or inconsistent with, its provisions. Such provisions of this Patent Policy as are inconsistent therewith shall be deem superseded and the provisions of such laws and regulation shall apply.

I. Patent Management Agencies

Cornell Research Foundation may make suitable arrangements not inconsistent with the provisions of this Patent Policy with patent management agencies or firms for the purpose of obtaining services and advice with respect to the patentability of inventions, the obtaining of patents thereon and the management and licensing of any such patents.

J. Patent Agreements

In order to facilitate a distribution of patent rights and benefits consistent with the provision of this Patent Policy, each participant in University Research shall execute a Patent Agreement. Pursuant to such Agreement each participant shall acknowledge that all such research is subject to the terms of this Patent Policy, and shall agree to cooperate with the University or its designee in the assignment to the University of patent rights in inventions or discoveries conceived or first reduced to practice during such research and the preparation and prosecution of patent applications, as may be required in order to implement its provision.

This requirement may be waived by the Vice President for Research only in those limited cases where University Research occurs within a discipline in which the prospect of a patentable invention is, in his or her judgment, extremely remote.

K. Patent Advisory Committee

The Vice President for Research shall, after consultation with the Research Policy Committee of the Faculty Council of Representatives, establish and appoint, subject to the approval of the Board of Directors of the Cornell Research Foundation, a Patent Advisory Committee which shall serve at his or her pleasure. It shall be the function of the Committee to advise and recommend to the Vice President for Research with respect to:

1. guidelines and procedures for implementation of this Patent Policy,
2. proposed amendments to the Patent Policy,
3. the granting of individual exceptions to this Policy,
4. the University's ownership of particular inventions,
5. such other matters as the Vice President for Research may deem appropriate.

The Vice President for Research shall report to the Board of Directors of Cornell Research Foundation and the President of Cornell University upon matters of significance relating to the administration of this Policy.

Notes:

1. Use of University office space or library facilities shall not constitute a use of University resources for this purpose.
2. For the limited purpose of this policy, staff members shall also include all research assistants, graduate research assistants, teaching assistants, fellows, students who provide services under sponsor agreements which require University ownership, and others who utilize University resources in the furtherance of their research.
3. The distribution provisions contained herein shall apply to all existing and future inventions. The distribution table contained at paragraph E(1) shall be applied on a cumulative basis to all net royalty income earned during the life of an invention, and not annually.
4. Direct expenses include the costs of obtaining patent protection for the particular invention and all marketing, promotion and licensing costs related to the particular invention.
5. Typically the inventor's Department, School, Section or Center.
6. Typically the inventor's College.

CASE STUDIES

In order to deepen our own understanding of the role of basic research in the innovation process and the ways in which companies and institutions employ and conduct basic research, CED asked its Trustee companies and universities to offer representative examples of basic research in their organizations. This section of the report contains a collection of these responses, assembled as a series of case studies. We believe they are enormously illuminating in their own right, and can be read with great interest independent of the report. But they also reinforce the findings contained in the Policy Statement.

AIDS RESEARCH AT MERCK & CO., INC.

(Prepared for CED by Merck & Co., Inc.)

America's pharmaceutical industry has achieved global leadership by discovering more life-saving medicines by far than any pharmaceutical industry of any other country. In the past 20 years, of all important drugs discovered and introduced globally, nearly half have come from U.S. companies. In the American wing of this important industry, Merck has long been at the forefront of innovation.

With this record of accomplishment in mind, it would be helpful to look at one of Merck's successful research programs for guidelines as to how the United States might sustain and strengthen its science-technology base. Particularly useful in this regard should be the recent experiences of the Merck Research Laboratories in discovering and developing Crixivan (indinavir sulfate), the company's new protease inhibitor for the treatment of HIV infection and AIDS.

Merck started this work in 1986, only three years after the virus that causes the disease had been positively identified. Scientists at NIH and elsewhere were making important progress, but much research remained to be done on a virus and disease that were still poorly understood. During the next ten years, Merck scientists helped improve the knowledge of both. They conducted studies that any university scientist would identify as basic or fundamental. These studies were tightly intertwined with research that was clearly developmental. All of Merck's research, basic or otherwise, was "applied" because it was directed toward the development of useful therapies for this deadly disease.

By way of contrast, when Merck launched its research in the mid-1970s aimed at developing inhibitors that would lower blood cholesterol, the laboratories were building on over 30 years of basic research into lipid biosynthesis. Most of that research had been conducted at the NIH or in research universities in the United States and abroad and very little of it would be classified as "applied." Its immediate goal was to develop a better understanding of fundamental biochemical processes, not to develop practical, effective therapies (such as Mevacor and Zocor, for persons suffering from hypercholesterolemia). That particular program and its outcome provides an excellent example of the kind of cooperative interaction among public, nonprofit, and profit-making institutions that has made the United States a leader in pharmaceutical innovation.

But in the case of AIDS, the pandemic was so serious, the public and public health authorities so correctly and deeply concerned, that Merck started a major, multi-pronged research program long before a solid foundation of basic research existed. Merck attacked the problem on several fronts because neither the Merck laboratories nor the scientists at NIH and the universities could predict with any degree of certainty which approach would be successful.

Merck tried for several years to develop a vaccine against HIV infection. The company was encouraged by the fact that its Virus and Cell Biology Research had successfully produced the world's first recombinant DNA vaccine against hepatitis B (Recombivax HB), as well as by the fact that Merck would be able to partner with biotechnology firms which could bring to bear their special expertise.[4] One of these firms, Repligen, discovered the V3 loop on the surface of the virus, and Merck's scientists tried to use that portion of the virus to make a vaccine. The company also probed the use of monoclonal antibodies (working with MedImmune) as a means of combating HIV infection. Both of these approaches failed. As Merck's vaccine researchers observed in 1990, "the mechanism by which initial virus infection occurs is not well understood...."[5] In lay terms, they were groping in the dark.

Today Merck is building upon fundamental research in the HIV vaccine field conducted by the Merck Research Laboratories and by others in the last five to six years. Merck's scientists have several new directions and technologies to explore. As their knowledge of the virus and the process of infection improved, they could see much more clearly what was likely to work and what was likely to fail. Virus and Cell Biology Research at Merck was able to refocus its vaccine program as a result. But due to the inadequate base of fundamental research on the immunology of HIV infection and HIV vaccinology, several years had been lost in the effort to develop a safe and effective vaccine.

Fortunately, during these same years, Merck and other companies were exploring several different paths to a successful HIV therapy. The major targets were the enzymes involved in the process by which the virus transcribes its RNA into proviral DNA, which is then integrated into the host cell's genetic material. One of these was reverse transcriptase, which controls the first step in viral replication. AZT (zidovudine) is one of the compounds that interrupts the HIV life cycle by inhibiting the natural nucleosides. But AZT's adverse side effects, relatively low antiviral potency, and the ability of the virus to develop mutations that conferred resistance to the drug prompted Merck's scientists to look for more effective, non-nucleoside analogue inhibitors of reverse transcriptase.

After screening about 23,000 compounds over a two-year period, Merck discovered several non-nucleoside inhibitors (RTIs). But as the early clinical trials indicated, the virus successfully mutated around these drugs, as it had around AZT.[6]

That put all of the pressure on the third branch of HIV research, which was focused on the protease enzyme. Some years earlier, federally supported cancer research had resulted in the publication of a paper analyzing the role a protease enzyme played in the spread of a virus associated with tumors in chickens. Merck scientists familiar with that research suspected a protease enzyme also played an important role in HIV replication. But they were not absolutely certain the protease was a good target until Dr. Nancy Kohl and her colleagues at the Merck Research Laboratories completed an elegant experiment that proved the protease was crucial to the replication of HIV. In the tradition of basic science, they published their findings in the *Proceedings of the National Academy of Science*.[7] Researchers at Merck and NIH then established the crystal structure of the protease. This research could have been considered proprietary information of value to competitors, but the firm's scientists also quickly made these findings available to others.[8]

As this work progressed, MRL researchers made other vital contributions to the understanding of the disease and its treatment. They conducted analyses of HIV turn-over and predicted on the basis of their study of one of Merck's non-nucleoside RTIs that HIV infection is a highly active, continuous process. As the subsequent work of David Ho at the Aaron Diamond AIDS Research Center, Tony Fauci at NIH, and Xiping Wei at the University of Alabama-Birmingham demonstrated, the virus replicates at a high rate and over years erodes the capacity of the immune system to keep it in check. Eventually, patients progress toward AIDS.

Prior to Crixivan, all anti-retroviral therapies had limited effectiveness insofar as they mediated only transient declines of plasma viral levels. We now know—due to the work of scientists at Merck, other pharmaceutical companies, NIH, and academic institutions—that these therapies failed because of the eventual selection of resistant viral variants. The research of Merck's Jon Condra and his colleagues pointed other scientists toward a new concept of the progression of the infection and the development of resistance in the presence of suboptimal antiviral therapy. Merck studies of viral resistance to Crixivan established that resistance requires the continued accumulation over time of multiple mutations: there is a high "genetic barrier" to resistance. Suppression of the ongoing replication made it less likely that the virus would develop the mutations it needed to produce resistance. Successful antiviral therapy, they established, had to reduce circulating viral RNA levels below the limit of detection in the available assays.[9] This perspective is now generally accepted and the desired decline has been achieved by patients using Crixivan in triple combination therapy (with AZT and 3TC).[10]

Were there other potential targets for HIV/AIDS research? Yes, scientists might have developed a fourth line of attack by targeting the integrase enzyme, which performs the function of incorporating the HIV genome in the host cells. This would have been another means of preventing HIV from infecting new cells. Until recently, however, little was know about the integrase enzyme. Additional resources funneled into basic research early on could have accelerated this aspect of the search for effective HIV therapies.

So too in basic vaccine research. Companies like Merck could have avoided some blind alleys and focused their resources more tightly on other targets if the basic research foundation had been broadened and deepened in the 1980s.

Given the initial lack of fundamental knowledge about the virus or disease, however, Merck can take considerable satisfaction in what has been learned and accomplished in the past decade. Throughout Merck there is great pride in having developed Crixivan. Without some elegant chemistry, a good measure of brilliant process research and engineering, and an unusually determined effort in the manufacturing division, Merck could never have produced enough of this complex molecule to complete clinical trials and then to treat the many patients who were desperately in need of therapy.[11] Nor could Merck have organized a compassionate use program for patients who had exhausted all other HIV therapies. This was done a full year before the FDA and other regulatory agencies worldwide cleared Crixivan for marketing.

For the present, it would suffice to say that throughout the years that it took Merck to develop this new drug, there was no visible seams and certainly no quality distinctions between research that others might categorize as basic or applied, fundamental or developmental. From the Company's point-of-view, it was all good medical science serving society, which has been Merck's central mission for over a century.

COLUMBIA UNIVERSITY AND VIMRx PHARMACEUTICALS

(Prepared for CED by Columbia University)

In 1996, Columbia University's research expenditures amounted to $232 million, the vast majority of which ($194 million) derived from federal grants and contracts. In recent years, however, a small, but growing, portion of the research effort at Columbia has involved collaboration with industry that has taken various forms (such as direct funding of research by industry, joint research projects, and partnerships in existing research centers).

Through the active efforts of the Columbia Innovation Enterprise (CIE)—a unit of the Provost's Office devoted to identifying, evaluating, protecting, and licensing intellectual property; encouraging technology transfer; and increasing private sector funding for research and development—Columbia has been exploring new forms of collaboration with industry. In the spring of 1997, Columbia and VIMRx Pharmaceuticals, Inc. reached agreement on an ambitious collaboration that could, if successful, form a model for similar partnerships at Columbia and elsewhere.

Under the terms of the agreement, a subsidiary of VIMRx (in which Columbia holds a 10 percent ownership stake) will have an option for exclusive licensing of technology developed at the Columbia Genome Center. In return, the VIMRx subsidiary will provide $30 million for research at the Genome Center over a five-year period. The Columbia Genome Center is a research unit devoted to mapping, sequencing, gene discovery, and technology development on the genomes of human and selected model organisms. The explosion of new technology and information on the structure of genes has permitted the localization and identification of novel human genes associated with many genetically based diseases; at the Columbia Genome Center, investigators have been at the forefront of the race to identify specific genes associated with such diseases as cancer, late-onset Alzheimer's Disease, epilepsy, manic-depressive disorder, and glaucoma. VIMRx is a development-stage company involved in the development of technology to treat and prevent disease by controlling disease-triggering flaws in the genetic chemistry of individuals.

Both parties to the agreement see potential benefits of the new arrangement which will permit the translation of forefront research results into useful, commercially viable medical products. VIMRx will have access to world-class research that it could not expect to carry out on its own; for its part Columbia will receive a significant infusion of research funding.

The collaboration will extend for a period of five years, after which Columbia and VIMRx will have an option to continue the arrangement indefinitely upon mutual consent.

As a case study in progress, the collaboration raises a number of questions and issues about university-industry interactions:

- Does participation in the broad research program of a university research center lead to more or different commercial benefits for a company than would more targeted funding of particular, individual research projects?

- Is the nature of the research undertaken by a university research center changed significantly by the need, real or perceived, to generate commercially viable research results? Is there a tendency to focus on more applied research? Is very basic research threatened?

- Are there effects on the traditional openness of university research that result from the proprietary demands of the commercialization process?

- Do arrangements such as this encourage other industries to participate in similar ways, or does an exclusive arrangement between a university and a particular company make it more difficult or less desirable for other companies to become involved?

PFIZER INNOVATION

(Prepared for CED by Pfizer Inc.)

Pfizer is a health care company committed to innovation as the key to improving the health and lives of people. Pfizer's products, such as Norvasc (for hypertension), Zoloft (for depression), Zithromax (for bacterial infections), and Diflucan (for fungal infections) have helped millions of patients worldwide. These products play a central role in treating their corresponding diseases by delivering quality outcomes which are much improved over those offered by earlier therapies. Unfortunately, many other conditions await safer, more efficacious, and more convenient treatments. Lack of such treatments results in disabilities, early deaths, decreased quality of life, and enormous economic costs. Aging of the population and rising cost pressures will create further demand of new, cost-effective health care solutions. These demands will be met by exciting new technologies for diagnosing, treating, and preventing illness which are now emerging from rapid advances in the basic biomedical sciences.

The Challenge of Basic Biomedical Research

These recent and ongoing advances have grown out of a long-term commitment to basic biomedical research conducted in universities, medical centers, research institutes, and government laboratories. Academic research in the biomedical sciences has focused on improving understanding of the human body, other organisms, and disease processes. In the course of addressing essential questions about how and why things occur, such research provides fundamental scientific insights into biological function. An example is the concept of apoptosis, or preprogrammed cell death, an apparently important component of many disease processes. Basic research also results in essential tools and techniques for conducting further research. Core technologies such as recombinant DNA/genetic engineering, nucleic acid amplification and probes, gene transfer, transgenic animals, cell culture, immunoassays, and monoclonal antibodies have both come out of and supported further basic research infields including molecular and cellular biology, microbiology/virology, immunology, neuroscience, physiology, pharmacology, and genomics. These technologies have subsequently been combined and applied in ways unforeseen by original researchers, opening up entirely new avenues of scientific inquiry and technical development.

A case in point is the Human Genome Project. Begun by the National Institutes of Health in 1990 with the goal of mapping and sequencing the entire human genome, this effort has been made possible by earlier, basic advances in fields as disparate as molecular biology, genetics, microbiology, computer science, and robotics. Harnessing the efforts of multiple academic centers, this effort will ultimately provide a basis for better understanding of underlying body function and disease processes by delineating the structure, function, and interaction of the genes which control the production of proteins, the key actors of biology. It has already provided intriguing insights into disease occurrence and process, such as breast and colon cancers and obesity, while spawning new technologies such as bioinformatics. Genomics is representative of how biomedical research continues to provide new methods and topics for investigation, while it also highlights the growing underlying complexity of health and disease knowledge.

Apart from providing basic laboratory tools, how does such academic research help lead to new disease therapies? From the perspective of drug discovery, understanding disease processes and structure in detail permits identifying points of intervention (mechanisms and targets). Similarly, work in pharmacology and organic chemistry may suggest particular or better approaches to accomplishing this goal (lead concepts). Finally, methods of assessing the validity and correspondence of particular targets and leads (assays) may utilize some of the core technologies mentioned. In addition to improving conventional small molecule drug development, genomic information will be crucial to developing new diagnostic and therapeutic modalities, including gene testing, peptide molecules, antisense (DNA blocker drugs), vaccines, and gene therapy. Academic medical research centers also provide the sites and patients for testing new therapies in clinical trials, which produce the ultimate assessment of their utility in patient care.

Pfizer's Response

Pfizer has responded to advances in basic science by seeking to harness and integrate these new technologies, while at the same time fostering interaction with academic researchers. In contrast to the explanatory focus of basic academic research, Pfizer's role centers on how to meet specific clinical needs through the applied and directed development of science and technology. By spending approximately $2 billion in 1997 on discovery and development of new drugs, a figure which has risen dramatically over the past decade, Pfizer seeks to integrate basic scientific findings and new technologies to discover and develop novel therapeutic agents meeting important patient needs. This represents an intrinsically prolonged, risky, and very expensive innovation process which must be actively managed. And this process is becoming even more expensive and risky with the rising complexity of underlying science and new disease states targeted.

How does basic biomedical research factor into Pfizer's discovery and development efforts? First and foremost is the central role that published scientific literature and meetings play in stimulating thought and generating ideas which promote the drug discovery and development process. Whether it is the structure of a receptor target or pharmacologically active compound, or some basic insight into pathophysiology, such work provides valuable input into Pfizer's directed efforts. Also, all of the new laboratory tools and technologies derived from earlier basic research have been incorporated by Pfizer into its drug discovery efforts. Finally, Pfizer scientists, who represent the most critical resource in this process, trained at universities by conducting basic research. And in a way which parallels the integration of core technologies in drug discovery and development, these scientists are now working in multi-disciplinary, cross-functional project teams which are able to leverage and pursue new developments more rapidly and efficiently.

Pfizer supports academic research through a variety of means, including research collaborations with financial support, fellowships, and unrestricted grants for basic research in synthetic organic chemistry. Pfizer also conducts large-scale clinical trials of drugs in development in collaboration with academic health centers.

Pfizer's methods and strategy for innovation have integrated basic research findings and technological tools to create a fundamentally new drug discovery and development process. Methods have focused on increasing productivity by increasing the overall volume of compounds assessed, while at the same time optimizing target selection. Pfizer has been a pioneer in incorporating genomic information into drug discovery. By providing insight into disease processes and targets, this information has been combined with high speed combinational chemistry (which creates vast numbers of potential drug-like compounds) and high throughput screening techniques (which tests them for possible drug properties by checking fit and correlation with targets), technologies derived in part from basic science research. Technology access strategy in this increasingly rich, complex, and fast-moving environment has focused on early stage collaborations with a variety of smaller, entrepreneurial firms and academic researchers. The total number of collaborations has reached 270, placing Pfizer in a position to understand and foster basic research. This approach gives Pfizer the flexibility to follow the directions and opportunities opened up by science, taking advantage of unforeseen spill-overs into new areas rather than being limited to specific, pre-set fields of development.

Pfizer has referred to these collaborative efforts as a "Web of R&D Innovation" which has produced tangible results. For each ongoing project, 1000 compounds a week can now be synthesized (versus 6 five years ago), while thousands of compounds can be screened each week. In 1996, 20 million such tests were performed on 100,000 compounds, yielding 18 new drug candidates. This represents 70 staff-years to generate a new drug candidate, compared to 100-250 staff-years for other firms. Use of these new technologies has effectively reduced time from initial idea generation (project start) to candidate nomination (preclinical development) from just over 4 to 2.3. staff-years, with an additional 12 months of study required prior to first human trials. Pfizer now has over 100 research projects underway - more than at any time in its history. Many of these gains have resulted in part from basic biomedical research. The final result will be more, innovative new drugs available to patients sooner.

Key Final Points

Some key lessons have emerged from this review of basic biomedical science research and Pfizer's corresponding role in medical technology development:

- Innovation is central to improving health and quality of life, resulting in important products which meet significant patient needs.
- Basic biomedical research plays a crucial role in providing a healthy environment for innovation by providing fundamental insights into normal body function and disease, developing new technological tool and techniques, and expanding human knowledge capital and skill base.

- Results of basic biomedical research are often creatively applied and combined in unforeseen and unpredictable ways, making short-term and directed planning approaches risky and likely detrimental to long-term innovation.
- Industry and academia each play vital yet different roles in this process, with industry focusing on integrating basic science findings in a directed, applied process of managed drug development, which has been transformed by new technologies and multi-disciplinary team approaches.
- This development enterprise is considerably different from the inquisitive, open-ended nature of basic academic research.
- Basic biomedical research needs continued support from all sources in order both realize its exciting current potential and chart new paths which will ultimately form the basis for future innovation.

PROCTER & GAMBLE BIO-ENGINEERED ENZYMES

(Prepared for CED by Procter & Gamble)

The use of enzymes in synthetic detergents goes back over 30 years to their first application in both Europe and the United States as a cleaning enhancement. Many difficult-to-remove stains, such as grass, blood, and fats consist of very large molecules that are more easily removed when their size is reduced. Enzymes such as proteases and lipases are extremely effective in selectively solublizing these stains and removing them.

Enzymes are well-established biological products derived from fermentation reactions. Their discovery, production and usage dates back to the original work of Louis Pasteur over 100 years ago. But enzymes are also difficult materials to make effective given their sensitivity to the reaction conditions created in a typical washing machine cycle. They are only active in a fairly narrow temperature range, are highly sensitive to the solution pH, and their catalytic performance is affected by trace contaminants.

Despite these limitations, enzymes were successfully introduced into detergents in 1960. While their performance enhanced the overall cleaning of the washing products, there were important concerns about allergic reactions due to inhalation. Inadequate industrial hygiene in some manufacturing facilities resulted in a low level of employee sensitization, and a concern about larger scale problems in the general population. These concerns resulted in a highly cautious approach to greater usage, higher performance levels or a broader range of enzyme materials. In 1974, the detergent industry voluntarily withdrew all enzymes from the market until the industry could assure their safety. They were not reintroduced until enzyme-containing particles were developed that essentially avoided the inhalation issue.

In the late 1970's the emergence of new science in biotechnology created the possibilities for bio-engineered materials tailored for specific applications, as well as the dream of much lower usage levels. The fermentation products successfully used up until this time were not well characterized. But advances in analytical chemistry—a P&G core competency—were now allowing a better understanding of the protein structure and composition of the most desirable materials. Nevertheless, the field of biotechnology was new to Procter & Gamble and it had to make a strategic decision on how to enter this new and exciting technical field.

A few highly committed technology managers and research scientists became convinced that Procter & Gamble could develop the expertise and exploit biotechnology effectively and safely in our consumer products. They set up a small biotechnology group by recruiting talent primarily from key departments in leading universities to augment experienced chemists on our staff. This became the catalyst for technical discoveries.

Early on, Procter & Gamble recognized that commercialization of basic scientific discoveries would require experienced industrial partners. Procter & Gamble approached the two leading companies, Novo in Denmark and Genencor in the United States, to propose joint development relationships. Genencor was at the leading edge in molecular modeling and gene transplanting. Novo was the most advanced in fermentation scale-up. Genencor, a small start up biotechnology company, was enthusiastic and Procter & Gamble worked initially with them. Novo became interested after initial product successes began to have an impact on their enzyme business. While Procter & Gamble was not known for its biological science expertise, its track record of commercializing new technology in products having a well established market success, and in large quantities, was appealing.

For nearly a decade Procter & Gamble jointly worked to develop a basic understanding of the biological sciences required to utilize recombinant DNA technology to tailor the genetic make up of the most promising enzymes. This allowed us to develop more effective, genetically engineered enzymes and gain some useful industrial experience with these materials. A key organization intervention was the linkage of the basic research organization with the scientists within the laundry technology group who would have responsibility to determine the efficacy of the new enzymes as soil removers in the laundry cycle. Then there was the final linkage to the product development groups worldwide. They had the ultimate responsibility to assess the final product performance and process conditions required to successfully manufacture bio-engineered detergents.

The culmination of this work was the identification of a unique, highly specific cellulase enzyme which was recently and exclusively introduced into P&G detergents worldwide. This new cellulase has the capability to selectively remove the fuzz and pills from frequently laundered color cotton garments that otherwise would look aged and worn. In doing so, this enzyme allows the original fabric color to show through. It, therefore, provides the "new fabric" color even after extensive washings.

To dimensionalize the technical challenge, we identified a single, highly effective cellulase from an enzyme cocktail. This unique material was successfully isolated, cloned and the entire process scaled up to a commercial level. Methods were developed to stabilize it in the detergent manufacturing process and tailor its usage for different fabrics in our key worldwide geographies. All this was done while solving the key technical and potential public relations problem of determining the correct level of enzyme so that the defuzzing and depilling process was no more detrimental to fabrics than other detergents.

In the process Procter & Gamble also learned that fuzz and pills became damaged after multiple launderings, and in addition to losing their dyes faster than the rest of the yarn, they inhibited the basic detergent cleaning process. That is, if clothes don't have damaged fuzz and pills they are less likely to pick up and retain dirt. So, what started out as a color-retention technology turned out to have an even larger benefit as a cleaning enhancement ingredient.

As Procter & Gamble has restructured its approach to basic research over many years, it has developed some effective guidelines.

First, constantly reach out for new scientific advances. While many discoveries occur entirely within Procter & Gamble's own lab walls, history says that no research organization has the full capability to make all of its own scientific discoveries.

Second, when an important emerging relevant technology appears, consciously create internal expertise and build a strong core technological base. To deal with the breadth of capable outside research organizations, core internal expertise is critical to maximize the value, choose relationships and transfer expertise.

Third, utilize the company's technology leads to attack the most important business problems. This is the linkage of technology and business strategies, or, marrying what's needed with what is possible.

Finally, commercialize technologies. It is important to drive new technology advances into superior performing products, packages and processes. This may entail the use of an external partner who can supplement our capability to accelerate speed to market. The innovation game is played in the marketplace. There are no wins in the labs! Great science is only effective if it results in new commercial opportunities. And the entire organization must realize this is the only true measure of its effectiveness.

HARVARD UNIVERSITY'S MIND/BRAIN/BEHAVIOR

(Reprinted with the permission of Harvard University)

Knowledge that Makes a Difference

Mind/Brain/Behavior (MBB) is a university-wide initiative at Harvard University that investigates the complex interaction of biology and culture that gives rise to human thought, feeling and behavior. If our brains are so similar, why are human beings so different? When and why do human beings act irrationally? How does the brain change over time? How do cultures and brains interact to influence health?

A collaborative effort among some of Harvard's leading faculty, MBB was created in 1992 by Harvard's President Neil Rudenstine along with four other Interfaculty Initiatives. He envisioned a Universitiy that could unite its nine distinct faculties and bring its vast but decentralized resources to bear on problems of importance to society. MBB helps realize this vision by focusing on questions and problems of human potential and vulnerability that require a creative uniting of forces because they fall between the cracks of traditional disciplinary inquiry.

MBB engages experts from diverse disciplines in explorations of themes relevant to our society. Imagine a discussion about drugs and addictions aimed at limiting the abuse of drugs and reducing the undesirable side-effects of prohibition, that avoids rhetoric and partisanship, and incorporates the latest research in neuroscience, psychology, criminology, and public policy.

Mind/Brain/Behavior represents an innovative approach to the study of human nature. MBB is committed to thinking about the implications and applications of knowledge as it is to the adventure of discovery. Where other institutions have brought neurobiologists together with pyschologists to advance knowledge about human beings, Harvard has cast its net far wider. MBB enables public policy experts, lawyers, theologians, physicians, anthropologists, historians, philosophers, and organizational researchers to join forces with laboratory scientists in neuroscience and psychology to develop projects that are innovative and designed to make a difference to institutional communities—from hospitals to schools to work organizations—outside the academy.

Faculty Fellowships and Working Groups

MBB's interdisciplinary work takes root in a Faculty Fellowship comprised of 35 scholars from across the University. The Fellowship gathers six times a year for a series of seminars and discussions centered on the complex interaction of biology and culture. The faculty have discovered that the single greatest barrier to effective collaboration is misunderstanding. Each scholar brings to the table assumptions, terminologies and ways of approaching problems that are unique to his or her discipline. These discussions enable faculty to exchange perspectives and methodological approaches in the service of generating new ideas.

Through their interactions in the Fellowship, faculty identify specific topics ripe for interdisciplinary investigation that no single discipline or department has managed to address effectively alone. Smaller collaborative groups—called working groups—are formed to enable more focused study of these topics. Each group is chaired by a faculty fellow and includes a broad cross-section of faculty from both within and outside the Harvard community. The working group topics fall into one of three broad categories: reason and emotion, learning and development, and health and illness.

MBB has already seen concrete results from its working groups. For example, the working group *The Brain in the Sociocultural World* produced a landmark conference and related book on the placebo-effect in healing. The *Drugs and Addictions* group recently briefed top federal officials on current issues in U.S. drug policy, and the working group *Early Brain Development* is planning a national conference on the brain bases for reading difficulties.

Research and Education

A committee comprised of members of MBB's Faculty Fellowship awards funds for innovative, cross-disciplinary research projects. Faculty members, students, and post-doctoral scholars working in the mind, brain and behavioral sciences are encouraged to submit proposals to the Research Committee. Recently funded projects include: the relationship between visual perceptions and mental processing and the neurobiological origins of anxiety and fear.

Faculty fellowship members have also created an undergraduate certificate program. The program is hosted in four departments in the College: biology, computer science, history of science, and psychology. The program integrates MBB coursework common in all departments, interdisciplinary seminar work, electives, and honors thesis. Innovative new courses designed by MBB faculty include: "Human Behavior and the Developing Brain;" "The Philosophy of Neuroscience;" "The Biology of Morality;" and "Remembering and Imagining."

Structure and Leadership

MBB is led by co-directors—a psychologist and an historian of science—and by a steering committee consisting of faculty from different schools. The directors set MBB's research and teaching priorities and oversee the Initiative's activities in consultation with the steering committee and with the Provost of the University.

Mind/Brain/Behavior is an ambitious experiment. In keeping with President Rudenstine's vision, MBB seeks to reconnect with life outside the university by uniting fractured faculties in the service of complex problems that matter to us all.

XEROGRAPHIC PROCESS RESEARCH

(Prepared for CED by Xerox)

This case study demonstrates the unpredictable, non-linear nature of the entire R&D process, as well as the way in which firms employ a "fill-in-the-gap" approach to conducting basic research. In this case, the need for fundamental scientific insights came after a product had already been brought to market. Yet, improvements in product performance were not simply a matter of fine-tuning; there were significant gaps in the knowledge of how certain processes worked that could only be addressed through basic research. The story unfolds over six decades, from Chester Carlson's invention in 1938 to the awarding of the 1997 American Institute of Physics Prize for Industrial Applications of Physics to a Xerox researcher.

The invention of xerography by Chester Carlson in 1938 represents one of the significant technology achievements of the 20th Century. Xerographic copying and printing has exerted a major impact on the democratization of information on a global scale. Although the basic requirements for xerography were identified by Carlson in his early work, the successful commercialization of the technology through the introductions of the Xerox 914 copier in 1959 required a number of subsystem and material engineering advances. In a six-year period following the invention, Carlson was unsuccessful in persuading 20 business equipment companies to consider the commercial development of the process. Finally, in 1944, Carlson established a working relationship with Battelle Memorial Institute, a private research foundation in Columbus, Ohio. Many advances were made at Battelle in xerographic materials and processes. Some notable inventions included two component developer (in which the toning powder was triboelectrically charged by mixing with larger carrier beads), amorphous selenium photoreceptors with 1000 times more sensitivity to light than the sulphur used by Carlson, and electrostatic transfer of the developed powder image to paper. The Haloid Corporation, a small photographic paper company in Rochester, New York, acquired a license to the process in 1947. Further technology advances enabled the marketing of several copiers in the '50s. The company's name was changed to Haloid-Xerox Corporation in 1955 and Xerox Corporation in 1961 following the wide market acceptance of the legendary Xerox 914 which automatically produced plain paper copies from an original page placed on the platen of the machine.

Although the first Xerox products introduced in the late '50s and early '60s were commercial successes, the scientific foundations of many of the xerographic process steps and materials were poorly understood. Up to this point xerography had been the province of inventors, technologists, and business people: it was now the turn of the scientists to analyze and extend the process to enable high copy speeds and improved copy quality. For example, the Xerox 9000 family of products, introduced in 1974, generated 120 copies per minute. A research center in Webster, NY was established in the mid-'60s for the purpose of studying the xerographic process to enable improvements in subsystems and materials. The intent was to spawn new products that embodied improved image quality, higher reliability, lower manufacturing cost and higher copying speeds. Major efforts were mounted to study charge carrier generation and transport in amorphous semiconductors, the electrical and rheological properties of toner (powder) materials processes for developing electrostatic images, gaseous ion charging physics, mechanisms of triboelectrification and particle adhesion, processes for fusing toner to paper, and cleaning methods for removing residual toner from the photoreceptor. Due to the multi-disciplinary nature of this effort, teams consisting of physicists, chemists, materials scientists, electrical engineers and mechanical engineers were assembled. The research efforts by Xerox and its competitors over the subsequent years have advanced the performance of xerographic technology to a level that approaches offset printing quality and productivity.

The xerographic research effort was organized around the individual steps in the xerographic process. These are: 1) photoreceptor charging, 2) light exposure to form an electrostatic image, 3) development of the electrostatic image with charged, pigmented poser (called toner), 4) electrostatic transfer of the developed toner to paper, 5) fixing of the toner to the paper with heat and/or pressers, and 6) cleaning of any residual toner from the photoreceptor before the next cycle. Research programs at Xerox have enabled significant advances in all of these process steps, as well as in photoreceptors themselves. This fact can be illustrated by exploring the chronology of advances in the performance of xerographic development systems.

The designs for xerographic development systems have gone through a number of generations since the cascade development system used in the Xerox 914 with two component developer. The two component mixture was cascaded over the photoreceptor to develop the electrostatic image. Only line copy and the edges of broad image areas were developed with this technique. To improve the development of broad image areas, the next generation of magnetic brush development systems was introduced in the early 1970s. The developer material consisted of polymer-coated, magnetic carrier beads which enabled the developer to be transported on a rotating roll containing stationary permanent magnets. The proximity of the roll to the electrostatic image on the photoreceptor and the brushing action of the non-conducting developer enabled improvement in the development of board image areas, a technique called two-component insulative magnetic brush development. Nevertheless, using this technique, the achievement of adequate image density development at high speeds (120 copies per minute) required a large development system with five development roles. To provide improved high-speed broad area development with a compact design, another generation of magnetic brush designs was introduced for which the carrier beads were made conducting for the purpose of bringing the effective development electrode closer to the electrostatic image on the photoreceptor. In this system, however, the effectiveness in developing fine features in the image was comprised compared to images developed with insulative magnetic brush development. In addition to the cascade and magnetic brush systems, other development system designs have been utilized for special applications. For low speed copiers and printers, single component development systems are widely used. In this case, the toner is triboelectrically charged by a metering blade in self-spaced contact with a rotating sleeve. For the development of colored images, most color development systems use a gentle magnetic brush of insulative two component developer in combination with an AC electric field to generate a toner cloud in the development zone. For each generation of these designs, extensive research has ultimately resulted in Xerox products.

Magnetic brush development system designs are favored for high-speed copiers and printers. The insulative magnetic brush systems provide excellent development of image details but are not efficient in developing broad image areas. On the other hand, conductive magnetic brush development systems are efficient in developing the broad areas, but compromise image detail. To understand the shortfall in the broad area performance of insulative magnetic brush development, the physics of two component developer materials and magnetic brush development systems was intensely studied at Xerox during the '70s and '80s. From this work, it was determined that the limitation on broad area development with a magnetic brush was due to a net carrier bead charge caused by toner deposition onto the photoreceptor. The identification of this limitation mechanism and a corresponding broad area development model provided important new insights into critical material and process parameters. In understanding the cause of the performance shortfall, a new system design called Highly Agitated Zone (HAZE) development was invented which provided both excellent broad area and image detail development with hardware that was smaller (fewer rolls) and lower cost. This design was first incorporated in a 62-copies-per-minute Xerox product, the Xerox 1065 Marathon copier, introduced in 1987. The product received "Product of the Year" awards for two years in a row.

Over the past 10 years, this product family has produced more than 100 thousand machines in the U.S. Furthermore, the HAZE design has subsequently been incorporated in several additional major Xerox product platforms for copiers and printers. Particularly noteworthy is the inclusion of the design in a highly successful family of high-speed (135 prints per minute) duplicators/printers introduced in 1988. The development system technology continues to play a key role in a number of new product offerings. The combined revenue from all of the products embodying this development system was nearly half of Xerox' total revenue in 1996. In recognition of the contribution of the HAZE development process to the success of three generations of Xerox' current products, and of the invention of further development systems likely to be used in Xerox' future products, the inventor of the process was awarded the 1997 American Institute of Physics Prize for Industrial Applications of Physics.

In summary, xerography evolved from the key invention of Chester Carlson and subsequent material and process inventions at Battelle which provided the foundation for copier products at the Haloid Company and ultimately led to the first automate electrophotographic copy machine, the commercially successful Xerox 914. The success of this product and the need to generate subsequent generations of improved versions motivated the establishment of a research laboratory organized around the xerographic process steps and devoted to generating an evergreen stream of improved xerographic marking engines for both copiers and printers. Improvements in each process step generated by research were incorporated into new subsystem designs which in turn were offered to the public in successive generations of Xerox copiers and printers during the past four decades. By way of an example, the generations of development system designs were reviewed to illustrate the sequence of advances driven by research programs.

A more detailed description of the HAZE process serves to illustrate how fundamental insights gained through basic research can result in superior product performance over multiple generations of products. Although this case study has emphasized the role of the development system design in contributing to the advanced performance of copiers and printers, comparable pay offs have been achieved with other xerographic materials and subsystems. The net result is that investments in basic research have provided a highly leveraged source of profits for generation after generation of Xerox products from the Xerox 914 to the recently announced Xerox 6180 digital press which incorporates the HAZE development system process to produce 180 prints per minute.

IBM RESEARCH

(Prepared for CED by IBM)

The Research function in IBM is located in three U.S. laboratories and four international laboratories in Beijing, Haifa, Tokyo, and Zurich. The technical population consists of nearly 2000 engineers and scientists, most of whom have PhDs. The scope of activities is broad as would be expected of a company covering nearly every area of information technology. In addition to work that address the product needs of the IBM businesses, there are activities in new and alternative technologies and areas of basic research that contribute to the scientific understanding underlying the technologies in our business. The largest part of the Research funding comes from corporate headquarters, followed by funding from the various IBM product and sales organizations. A very small amount of funding comes directly from the outside in the form of government contracts and occasional external revenue sources.

Research remains organizationally independent from IBM's development functions, creating both opportunity and responsibility with respect to its role in the IBM Corporation. Such independence permits the division to explore new technologies and applications, carry out basic research, and provide independent technical advice to IBM regarding current and future product directions being undertaken by the product groups. With such independence goes the responsibility of contributing recognized value to the IBM corporation through such means as creating intellectual property, creating and developing leadership technologies for rapid infusion into the IBM product line, enhancing IBM's technical image through public awareness of its world class science and technology, and creating a technical view of the future that can provoke and guide the product and sales groups in the creation of their business strategies. To carry out our mission in IBM, Research works with more than 30 organizations within the corporation.

To be a successful research organization requires that the right programs be defined and that these programs be effective, both in carrying out the research but also in translating the results into values that can be leveraged by the rest of the company.

The Research planning process begins with an annual exercise to identify the future trends of the information technology business. Although focused on the basic technology trends, e.g. the reduction of size and increased speed of circuits or capacity of storage, societal and business trends are also examined in order to define the external environment within which IBM will exist in the near future. Although IBM science and exploratory programs often create the game changers for its industry, Research is keenly aware that many of the major changes come from laboratories and companies outside IBM and therefore we expect our professionals to be tuned to the external science and technology communities. The need for a clearer view of the future, particularly in areas other than basic technology, has motivated Research to establish a small group of specialists in long term market planning. Using this view of the future, IBM's technical strategists prepare plans for the year that take into account not only the anticipated trends but also the nearer term requirements of the IBM units with which it collaborates to provide technical leadership in IBM's product lines.

Having created an annual plan of activities it remains for the management to monitor and track the success of the research in delivering value to IBM. At the end of each year, the top division management gathers to review the work of the year. The review includes evaluations by other IBM divisions regarding delivery of results, the degree to which collaborative relationships have been successful in delivering needed technology and direction to other parts of IBM (alignment of strategy, people relationships, etc.), the number of U.S. patents filed for the year, the number of external awards and other recognition received by IBM researchers (Nobel prizes, National Medals, Fellows, etc.), and self assessments of key results for the year, both in the field of science as well as those affecting IBM. These measures are taken quite seriously by both the management and non-management research personnel, as the final result gets translated into compensation for Research employees. Most importantly, this thorough review of Research's activities is an excellent source of feedback about how well IBM research is contributing to the company.

BBN AND THE DEFENSE ADVANCED RESEARCH PROJECTS AGENCY

(Prepared for CED by BBN/GTE Internetworking)

Maintaining the nation's economic well-being and preserving its security are two of the federal government's most important responsibilities. It has long been recognized—and often established as public policy—that innovation and technological preeminence contribute to both goals by creating new capabilities, and giving rise to new industries and jobs. Nowhere is this more evident than in the development of computer technology; and no office of government has been more effective in this arena than the Defense Advanced Research Projects Agency (DARPA).

Originally created as the Advanced Research Projects Agency (ARPA) by President Dwight Eisenhower shortly after the Soviet Union launched its first Sputnik satellite in 1957, it was designed to be a fast-response, R&D mechanism that would ensure American leadership in future technologies. Over the years, however, ARPA shifted its focus to "high-risk, high-payoff," long-term basic research, and research sponsorship of new ideas. By drawing talent from the nation's finest universities, public, and private research laboratories—and by allowing scientists to apply their ideas through experimentation—ARPA built a community that included some of the best technical and scientific minds in American research.

For more than thirty years, BBN Technologies has been a vital member of that community, and its long and productive relationship with the agency has led to a host of innovations; most notably the ARPANET, the forerunner to the Internet. At the time of the network's development in the late 1960s, agency scientists were using different computers, running different operating systems, in different parts of the country. ARPA reasoned that, by electronically linking these machines, researchers at various institutions could more easily share resources and results. But that would require building an experimental network based on packet switching—a new method of transmitting data by dividing electronic messages into small, uniform segments.

When ARPA sent out its request for proposals to develop the packet switches—which were first called Interface Message Processors (IMPs)—BBN responded with an extensive and detailed description of the entire network, incorporating test programs and performance checks, explanations of how to handle congestion and recover from computer and line failures, and computations, equations, and tables dealing with queuing of packets and transmission delays. Once it was chosen for the job, the Company's engineers designed the software to form a fully integrated network. They studied interactions among programs to ensure the actions taken by one program did not conflict with actions taken by others. And they created a system where the components worked together smoothly, so most users did not sense its underlying complexity. By the early 1970's, BBN had successfully developed and quickly expanded the first network of packet switches.[12] But it took more than IMPs to make the emerging network truly useful.

The initial goal of designing, implementing, and fielding the ARPANET generated new interest in the kinds of protocols and distributed computing technology that could further enhance the utility of the experimental network. By 1975, protocol investigation within DARPA led to the concept of a network of networks—which ultimately became the Internet—and to TCP/IP as a means for universal interconnection. At the same time, BBN, as part of both DARPA's research community and the university computer science research community at large, began investigating the impact of computer-to-computer communication capabilities on new applications such as distributed air traffic control and unified medical records across hospitals; and on the operating systems software needed to deliver communication services to those applications.[13, 14]

Early work in these areas proved conclusively that such applications were complex and difficult to build. This led to two parallel tracks of development. One concentrated on the direct implementation of a very limited set of immediately useable applications, including e-mail, telnet, and ftp; while the other focused on additional infrastructure to enable more general-purpose applications to be developed using wide area communications capabilities. The latter activity spawned what has come to be known as "middleware," because it was strategically placed between the network and the application to provide a richer, simpler network environment for a wide variety of uses.

With continuing DARPA support, and employing the experimental method championed by the agency to test and refine new ideas, BBN developed, tested and evaluated two generations of middleware systems throughout the later part of the 1970's. The first generation provided solutions for distributed computing in a homogeneous systems environment, based on a message-passing paradigm. The second perfected this work and developed additional solutions for a more general, heterogeneous system environment. But one that was based on a remote procedure-call form of orientation. Though these technical investigations were very successful, the impact of applying them economically on the prevailing computer technical infrastructure was less so.

Indeed, the computing landscape at the time was shifting from one of a few large computer systems to many smaller, cheaper systems enabled by innovations in chip fabrication; and from a few large networks to many smaller, locally managed networks enabled by technologies such as Ethernet. Moreover, the transformation from a programming environment dominated by custom assembly language to a variety of high level languages (e.g. "C," Lisp), enhanced the conception and execution of more complex applications. It was becoming clear that the proliferation of new technologies would depose many of the older computing hierarchies. It was clear, too, that middleware would have to change to keep pace with the size, scope and variety of the computer technology base.

Consequently, BBN's third generation middleware system, Cronus, which began in 1981, was based on the development of distributed object computing.[15] This approach also enabled The Company to address the challenge of creating complex, distributed applications in an extensively heterogeneous and rapidly changing environment. The sort of environment required by the military to effectively operate the variety of new computer and communication technologies which were fast being developed and adopted.

As BBN's knowledge of the middleware technology matured, financial support for developing a new distributed, object-based, middleware infrastructure moved to the Air Force Rome Laboratory. By the mid-1980's, BBN engineers had a working Cronus system suitable for evaluation and use by government projects. The first trials involved developers working with early adopters on prototype concept demonstrations. Each led to further refinements in the technology, and to better understanding of how it could be used by application developers. In the late 1980's, the Navy's San Diego R&D Lab joined its Air Force counterpart in testing the technology on operational problems that were being addressed by BBN application developers for a number of Navy and DARPA programs.

These trials were extremely successful and fielded new network-based capabilities quickly and cost-effectively, particularly when compared with non-middleware-based development projects. Distributed application engineers at BBN worked with Department of Defense (DoD) contractors and operational personnel to deploy systems such as CASES, TARGET, and DART, and were able to tackle significant operational issues for distributed command-and-control applications.[16, 17] Along with conducting various tests and evaluations, they trained DoD contractors and university engineers, programmers, and system management personnel to use the new technology. Subsequently, the systems were incorporated into advanced concept demonstrations by other DoD and DARPA contractors. Universities and industrial research labs also synthesized the results with their own technical investigations, further extending middleware's use and refinement.[18] Over time, successes such as these, in distributed object computing, led to several large-scale, distributed integration programs making world wide military command-and-control operations more responsive and cohesive.

By the start of this decade, capabilities like those of Cronus began to appear in commercial products from major companies such as Digital, IBM, SUN Microsystems, and Microsoft, as well as from small startup firms. But because no two systems were alike, operating between them was extremely difficult. To remedy the situation, commercial vendors and users of distributed object technology joined forces to set acceptable industry standards. They formed the Object Management Group, and established the Common Object Request Broker Architecture, or CORBA. Their grassroots efforts attracted a great deal of interest, first, from vendors, and then from users who saw it as a way to voice their requirements for the newly emerging commercial offerings. In time, Cronus was adapted to the CORBA standard and given the new name Corbus.

Since its development, middleware technology has played a major role in the growth of distributed networks, including the Internet. In fact, the World Wide Web is, itself, a specialized form of middleware. Prior to its emergence, many people only saw utility for middleware and distributed applications in the context of local area computing. Now, with the increasing popularity of the Internet, middleware becomes even more important as a means to simplify, and more effectively manage, an extremely complex environment. In addition to the Web, there is also Java, with its own brand of middleware, to compete with DCOM and CORBA, and scores of narrowly specialized technologies employing middleware solutions.

Today, middleware represents just one of sundry successes that have resulted from the long relationship between BBN and DARPA that have continually raised the technology bar. Just as important, it is a notable example of how the transition from basic to applied R&D is not always well-delineated. This occurs in many fields, but it is especially true in computer science, where systems are man made and abstract in nature, and differ considerably from the more familiar patterns associated with the physical sciences. Innovations such as middleware actually combine basic and applied activities simultaneously. While the earliest investigations represent fundamental research, in that they seek functional organization of ideas and abstractions, the later tests, evaluations and refinements are clearly applied, because they identify particular uses and users, and establish practical applications. This is often the case for many DARPA-sponsored programs, which are intended, not only to develop potential capabilities, but to demonstrate—early on—the feasibility of new concepts prior to their actual widespread acceptance and availability.

Page 5, James Q. Riordan

I would add another paragraph to this list stating that while federal support for basic research is necessary, we also need to have basic research conducted in the United States by the private sector. In the past, CED has supported tax incentives for private research. This report does not call for such incentives. We should, however, call for the elimination of all tax disincentives for U.S. research. Every dollar spent on research in the United States should be treated as a U.S. source deductible expense in computing taxable income and available foreign tax credits.

NOTES

CHAPTER 2

1. The Procter & Gamble case study (see Case Studies section) illustrates the necessity for diverse basic research activities to meet innovation goals. P&G saw promise in biological research, a scientific field in which the company previously had no expertise. Recognizing the potential, they developed a basic research capacity in this area, primarily through cross-industry alliances, with a considerable payoff in the form of a better detergent product.

2. As explained in Box 2 on page 12, these characteristics of basic research, including the economic benefits that flow to those not involved in the discovery, provide justification for government funding.

3. The theoretical framework for these growth studies was developed in the 1950's by Robert Solow of the Massachusetts Institute of Technology, who was awarded a Nobel Prize for his work. The pioneering empirical work in this area was undertaken by Edward Denison while he worked for the Committee for Economic Development. See Edward F. Denison, *The Sources of Economic Growth in the United States and the Alternatives Before Us*, (Washington, D.C.: Committee for Economic Development, 1962).

4. Dale W. Jorgenson "Investing in Productivity Growth," in Technology and Economics, (Washington, D.C.: National Academy Press, 1991), p.59.

5. The new theory is associated with the work of Paul Romer of Stanford University. For a brief summary of these issues, see J. Bradford DeLong, "What Causes Economic Growth?" (paper prepared for a symposium on tax policy sponsored by the American Council for Capital Formation, Washington, D.C., December 5, 1996).

6. "The internal rate of return provides a concise method for comparing different investments. Suppose, for example, the R&D investor could alternatively invest in a savings account with a constant interest rate. The internal rate of return on the R&D investment answers the question: what would the interest rate on the savings account have to be in order to make the investor indifferent between putting the investment in the savings account and making the R&D investment?"

7. Most rate-of-return studies use an R&D measure rather than a more narrowly defined basic research measure.

8. M.I. Nadiri, *Innovations and Technological Spillovers*, Working Paper no. 4423, (Cambridge, Mass.: National Bureau of Economic Research, 1993). Nadiri's consensus estimate was derived from a survey of 63 rate of return studies.

9. *MIT: The Impact of Innovation*, A BankBoston Economics Department Special Report, (March 1997). "MIT-related companies" are firms founded by MIT graduates.

10. E. Mansfield, "Academic Research Underlying Industrial Innovations: Sources, Characteristics, and Financing," *The Review of Economics and Statistics* 77 no. 1, (1995), pp. 55-65.

11. Francis Narin, Kimberly S. Hamilton, and Dominic Olivastro, "The Increasing Linkage Between U.S. Technology and Public Science," Research Policy, 26(3) (1997) 317-330.

12. For examples of this "new thinking," see Terence Kealey, The Economic Laws of Scientific Research, (New York: St. Martin's Press, 1996), and "What Price Science?" *Business Week*, 26 May 1997.

13. Microsoft's Bill Gates has suggested that the scientists who are currently sequencing DNA might provide the "algorithms" in carbon that can be transferred to silicone for purposes of creating a "computer that learns." Remarks made at the American Association for the Advancement of Science Annual Meeting, February 1997, Seattle, Wash.

14. Total basic research spending from all sectors was $31.2 billion for 1997 and GDP in that year was $8,083 billion.

CHAPTER 3

15. According to the National Science Board, federal government support for basic research was $17.1 billion in 1995 (59 percent of total support), industry support was $7.5 billion (25 percent of total support), and other support. including universities' own funds, nonprofits, and state/local governments, was $5 billion (17 percent of total support). National *Science Board, Science & Engineering Indicators*—1996 (Washington, D.C.: U.S. Government Printing Office, 1996), NSB 96-21.

16. Bush was the wartime director of the Office of Scientific Research and Development. His influential 1945 report, "Science, the Endless Frontier," was an important point of reference for post-war R&D policy.

17. Harvey Brooks and Lucien Randazzese, "University-Industry Relations: The Next Four Years and Beyond," in *Investing in Innovation: Creating a Research and Innovation Policy That Works*, ed. Lewis Branscomb and James Keller, (Cambridge, Mass.: MIT Press, 1998).

18. Brooks and Randazzese, "University-Industry Relations: The Next Four Years and Beyond."

19. The industry case studies section illuminates the way in which industry views basic research.

20. Before passage of the Bayh-Dole Act, there was no government-wide policy concerning ownership of inventions made under federal funding. Agencies were generally reluctant to grant ownership rights to an invention to the inventing institution. Bayh-Dole and subsequent amendments to it, all of which were finalized in 1987, made it government-wide policy to grant such rights. Bayh-Dole and its related amendments today constitute the "operating manual" for technology transfer offices at universities and other institutions receiving federal research funds.

21. Universities' licensing of their intellectual property has resulted in a rapidly expanding source of revenue, though still very small relative to total research dollars. According to the Association of University Technology Managers, royalties on licenses were $274 million in 1995 for surveyed universities, an increase of 108 percent from 1991 (see also Figure 3, page 23). The survey sample includes 87 of the top 100 research universities in the United States, ranked according to research dollar volume.

22. In "Research Universities and the Marketplace," (page 22), we discuss the problems that can arise as a result of university-industry partnerships and the patenting of university research. In Chapter 4, we offer principles which we believe provide the appropriate safeguards to facilitate technology transfer without impeding basic research.

23. Wesley Cohen, Richard Florida, Lucien Randazzese, and John Walsh, "Industry and the Academy: Uneasy Partners in the Cause of Technological Advance," in *Challenges to Research Universities*, ed. Roger Noll, (Washington, D.C.: Brookings Press, 1998).

24. Medical school professors are a notably large exception; many are clinical professors with minimal or no teaching responsibilities. See Linda Cohen, "Biomedical Research Support and the Decline of Medical Services Research Subsidies at Medical Schools," in AAAS Science and Technology Policy Yearbook, (Washington, D.C.: AAAS, 1998).

25. One-quarter of scientists and engineers who have received government support have obtained funding from more than one federal agency. See National Science Board, Science & Engineering Indicators—1996 (Washington, D.C.: U.S. Government Printing Office, 1996), NSB 96-21.

26. National Science Board, Science & Engineering Indicators—1996 (Washington, D.C.: U.S. Government Printing Office, 1996), NSB 96-21.

27. National Science Board, *Science & Engineering Indicators—1996* (Washington, D.C.: U.S. Government Printing Office, 1996), NSB 96-21.

28. This competition for researchers is not limited to universities. Prominent researchers can be the focus of intense competition between universities and other nonprofit research institutes. As we describe in "Nonprofit Institutions," (page 26), these nonprofits can be attractive alternatives for researchers because of lower fund-raising and administrative burdens. In this way, competition between universities and the nonprofits puts pressure on universities to keep these burdens to a minimum.

29. National Science Board, *Science & Engineering Indicators—1996* (Washington, D.C.: U.S. Government Printing Office, 1996), NSB 96-21.

30. Over the life of the patents, which expired on December 2, 1997, the universities expect revenues to total over $220 million from 369 licensees.

31. Wesley Cohen and Lucien P. Randazzese, "Eminence and Enterprise: The Impact of Industry Support on the Conduct of Academic Research in Science and Engineering," (working paper, Belfer Center for Science and International Affairs, John F. Kennedy School of Government, Harvard University, 1997); David Blumenthal, Nancyanne Causino, et al., "Relationships Between Academic Institutions and Industry in the Life Sciences — An Industry Survey," *The New England Journal of Medicine*, (February 8, 1996); Walter Powell and Jason Owen-Smith, "Universities and the Market for Intellectual Property in the Life Sciences," *Journal of Policy Analysis and Management*, Vol (17) No (2), pp. 253-277. For a summary of studies in this area, see Harvey Brooks and Lucien Randazzese, "University-Industry Relations: The Next Four Years and Beyond," in *Investing in Innovation: Creating a Research and Innovation Policy that Works*, ed. Lewis Branscomb and James Keller (Cambridge, Mass.: MIT Press, 1998).

32. Basic research conducted by the federal government accounts for 9 percent of total basic research in the United States (NSF, Science and Engineering Indicators 1996, Appendix Table 4-5).

33. *The Washington Post*, 11 September 1997, p. A23.

34. In this case, the federal subsidy does not come directly from an allocation of federal dollars for the project. Industry will provide the cash resources to cover salaries and other expenses. Nonetheless, there is a substantial indirect federal subsidy involved in making the three national labs available for the project.

35. See Kenneth M. Brown, *Downsizing Science: Will the United States Pay a Price?*, (Washington, D.C.: The AEI Press, 1998). Brown provides a thoughtful discussion of the "twin" problems that plague the labs: disappearing missions and bad management.

36. Secretary of Energy Advisory Board, Task Force on Alternative Futures for the Department of Energy National Laboratories, *Alternative Futures for the Department of Energy National Laboratories* (February 1995), p. 41.

37. The most prominent are the 1983 Federal Laboratory Review Panel, chaired by David Packard, and the task force chaired by William Galvin, which produced the 1995 report *Alternative Futures for the Department of Energy Laboratories*.

38. The IBM case study (see Case Studies) indicates that IBM scientists must be tuned in to research occurring outside of the company, even though IBM performs a great deal of basic research in-house.

39. See the CED policy statement, *Connecting Students to a Changing World: A Technology Strategy for Improving Mathematics and Science Education* (1995).

40. National Assessment Governing Board, *What Do Students Know? 1996 NAEP Science Results for 4th, 8th, & 12th Graders* (Washington, D.C.: NAGB, 1997).

41. Results reported for high school seniors. Ina V.S. Mullis et al., *Mathematics and Science Achievement in the Final Year of Secondary School: Third International Mathematics and Science Study* (Chestnut Hill, Mass.: Boston College, 1998).

42. National Science Board, *Science and Engineering Indicators*, 1996.

43. Committee on Science, Engineering, and Public Policy, *Reshaping the Graduate Education of Scientists and Engineers*, (Washington, D.C.: National Academy Press, 1995).

44. Between 1973 and 1993, the number of full-time faculty appointments for doctoral scientists and engineers grew by 67 percent. During the same period, postdoctoral appointments rose by 223 percent and part-time faculty appointments increased 95 percent.

45. National Science Board, *Science & Engineering Indicators—1996* (Washington, D.C.: U.S. Government Printing Office, 1996), NSB 96-21.

CHAPTER 4

46. National Science Board, Science & Engineering Indicators—1993, (Washington, DC: U.S. Government Printing Office), 1993, p. 139.

47. Walter Powell and Jason Owen-Smith, "Universities and the Market for Intellectual Property in the Life Sciences," *Journal of Policy Analysis and Management*, Vol 17 No (2), p. 268.

48. As we argue later in this chapter, some projects prove to be too expensive to support at the national level and should be pursued in conjunction with other countries.

49. The President's 1999 budget proposal would increase the funding disparity. Of the proposed $1.2 billion increase in basic research funding between 1998 and 1999, $616 million (just over half) would go to the NIH basic research budget. This would raise NIH's share of the federal basic research budget slightly, from 46 percent to 47 percent. See *AAAS Analysis of R&D in the FY 1999 Budget*, available at www.aaas.org on the Internet.

50. As described in Appendix 1, Medicare and Medicaid have been important sources of funding for research at university medical centers and, indirectly, a significant source of funding for university research in general. Structural reforms in these programs may result in less research funding from these sources.

51. See Roger Noll and William Rogerson, "The Economics of University Indirect Cost Reimbursement in Federal Research Grants," in *Challenges to Research Universities*, ed. Roger Noll, (Washington, D.C.: Brookings Press, 1998). Noll and Rogerson provide an analysis of the cost reimbursement problem and justification for a "benchmarking" alternative to the current system.

52. National Academy of Sciences, *Allocating Federal Funds for Science and Technology*, Committee on Criteria for Federal Support of Research and Development, (Washington, D.C.: National Academy Press, 1995), pp. 25-26.

53. National Science Board, *Science & Engineering Indicators—1996* (Washington, D.C.: U.S. Government Printing Office, 1996), NSB 96-21, pp.4-28.

54. CED has recently proposed remedies for the Social Security component of entitlements. See *Fixing Social Security* (March 1997).

55. See Kenneth M. Brown, *Downsizing Science: Will the United States Pay the Price?*, (Washington, D.C.: The AEI Press, 1998).

56. Data are for 1995. NSF, *NSF Data Brief*, 1997 no. 3 (March 13, 1997); U.S. Department of Labor, *Monthly Labor Review* (January 1998), Table 43.

57. See the CED policy statements *Putting Learning First: Governing and Managing the Schools for High Achievement* (1994), *Connecting Students to a Changing World: A Technology Strategy for Improving Mathematics and Science Education* (1995), and *The Employer's Role in Linking School and Work* (1998).

58. Some have suggested that agencies that sponsor research (such as the NSF, NIH, and the Department of Defense) could provide a significant boost to mentoring, internship, and other educational outreach initiatives by providing additional resources to research institutions for these purposes.

59. For a recent discussion of this issue, see Committee on Science, Engineering, and Public Policy, *Reshaping the Graduate Education of Scientists and Engineers* (Washington, D.C.: National Academy Press, 1995).

60. Committee on Science, Engineering and Public Policy, *Reshaping the Graduate Education of Scientists and Engineers*. See also Committee on Science, Engineering and Public Policy, *Advisor, Teacher, Role Model, Friend: On Being a Mentor to Students in Science and Engineering*, (Washington, D.C.: National Academy Press, l997).

61. Equally discouraging for new doctorates and those considering doctorates are certain aspects of today's academic research environment. As described in Chapter 3, the administrative and grant-raising burden placed on university researchers has become a formidable disincentive to pursuing academic research careers. See "Problems and Solutions in the Administration of Federal Grants for University Research," page 36, for recommendations in this area.

62. Immigrant scientists have long been very important to American basic research, particularly during and following World War II. Between 1933 and 1970, 27 of the 77 Nobel Prizes awarded to the United States went to first-generation Americans (Eric Hobsbawm, *The Age of Extremes*, New York: Pantheon Books, 1993).

63. National Science Board, Science & Engineering Indicators—1996 (Washington, D.C.: U.S. Government Printing Office, 1996), NSB 96-21, Appendix Table 2-35.

APPENDIX 1

1. See Bureau of Economic Analysis, U.S. Department of Commerce, "A Satellite Acount for Research and Development," *Survey of Current Business*, November 1994.

2. See, *Fixing Social Security* (1997).

3. See Linda Cohen, "Soft Money, Hard Choices: Research Universities and University Hospitals," in *Challenges to Research Universities*, ed. Roger Noll (Washington, D.C.: Brookings Institution Press, 1998)

CASE STUDIES

4. Merck had partnered with Chiron and with zymogenetics in the development of Recombivax HB.

5. *Science*, 249, 932-35.

6. Eventually, Merck discovered a non-nucleoside RTI that was licensed to the DuPont Merck Pharmaceutical Company in 1994 for clinical development and certain marketing rights. This compound, efavirenz [Sustiva (DuPont Merck); Stocrin (Merck)], can significantly reduce viral load and enhance immune system function in patients with HIV infection when used in combination with Crixivan and other HIV anitviral drugs.

7. Nancy E. Kohl et al., "Active Human Immunodeficiency Virus Protease Is Required for Viral Infectivity," *Proceedings of the National Academy of Science 85* (July 1988): 4686-4690.

8. Manuel A. Navia et al., "Three-dimensional Structure of Aspartyl Protease from Human Immunodeficiency Virus HIV-1," *Nature* 337, no. 6208 (February 16, 1989): 615-620.

9. Jon Condra et al., "Genetic Correlates of Viral Resistance to the Human Immunodeficiency Virus Type 1 Protease Inhibitor Indinavir," *Journal of Virology 70* (1996): 8270-8276.

10. See Scott M. Hammer et al., "A Controlled Trial of Two Nucleoside Analogues Plus Indinavir in Persons with Human Immunodeficiency Virus Infection and CD4 Cell Counts of 200 Per Cubic Millimeter or Less," and Roy M. Gulick et al., "Treatment with Indinavir, Zidovudine, and Lamivudine in Adults with Human Immunodeficiency Virus Infection and Prior Antiretroviral Therapy," both in *The New England Journal of Medicine* 337 (September 11, 1997): 725-733 and 734-739, respectively.

11. For a discussion of the chemistry, see Paul J. Reider, "Advances in AIDS Chemotherapy: The Asymmetric Synthesis of Crixivan," Chimia 51 (1997): 306-308.

12. F.E. Heart, R.E. Kahn, S.M. Ornstein, W.R. Crowther, and D.C. Walden, "The Interface Message Processor for the ARPA Computer Network," Proceedings of AFIPS 1970 Spring Joint Computer Conference, Vol. 36, June 1970.

13. R.H. Thomas and D.A. Henderson, "McRoss- A Multi-computer Programming System," Proceedings of AFIPS 1972 Spring Joint Computer Conference, Vol. 40, June 1972.

14. R.E. Schantz, "Operating System Design for a Network Computer," Ph.D. Thesis, submitted to State University of New York at Stony Brook; Computer Science Technical Report #28, May 1974.

15. R.E. Schantz, R.H. Thomas and G. Bono, "The Architecture of the Cronus Distributed Operating System," Proceedings of the 6th International Conference on Distributed Computing Systems, Cambridge, Massachusetts, May 1986.

16. B.M. Anderson and J.P. Flynn, "CASES: A System for Assessing Naval Warfighting Capability," Proceedings of the 1990 Symposium on Command and Control Research, SAIC Report 90/1508, June 1990.

17. J.C. Berets and M.A. Dean, "Building Object Oriented Distributed Applications Using Cronus," Proceedings of the IEEE Dual Use Technologies and Application Conference, Utica, New York, May 1994.

18. J.R. Nicol, C.T Wilkes, R.D. Edmiston, J.C. Fitzgerald, "Experiences with Accommodating Heterogeneity in a Large Scale Telecommunications Infrastructure," Proceedings of the 3rd Symposium on Experiences with Distributed and Multiprocessor Systems, Newport Beach, CA, March 1992.

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EVA	Centre for Finnish Business and Policy Studies Helsinki, Finland
FAE	Forum de Administradores de Empresas Lisbon, Portugal
FDE	Belgian Enterprise Foundation Brussels, Belgium
IDEP	Institut de l'Entreprise Paris, France
IW	Institut der Deutschen Wirtschaft Cologne, Germany
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