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ABSTRACT

Problems of international economic competition, environmental degradation, and quality of life demand the very best form the United States research community. New information assembled by the American Association for the Advancement of Science (AAAS) documents a deeply troubled mood among university researchers, even those who have been successful in pursuing research careers in prestigious institutions. This troubled mood is so pervasive that it raises serious questions about the very future of science in the United States. The results of an informal survey by the AAAS on the state of academic scientific research in the United States are presented in this report. Asked about their personal experiences with research funding, the respondents portray an environment of slow, but steady erosion. Sections in this report include: (1) "The Survey"; (2) "Why is the Morale of American Scientists So Low?"; (3) "Impacts of the Funding Situation"; (4) "Why Keep Science Healthy?"; (5) "How Much Research Do We Need?"; (6) "An End to the Frontier?"; and (7) "Conclusions and Recommendations." (KR)

A Report from
Leon M. Lederman, President-Elect
to the Board of Directors
of the
American Association
for the Advancement of Science
1333 H Street, NW
Washington, DC

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# Preface

The importance of scientific research to the well-being of the nation has long been recognized by U.S. policymakers. Since the mid-1980s, in the face of enormous pressures on the budget, federal investment in basic research has grown significantly—faster, in fact, than nearly any other area of non-defense government spending. In spite of this, evidence of low morale in the scientific community has been building steadily during this period in press reports, in Congressional testimony, in op-ed pieces, and in other public forums.

In recent months, these reports have taken on a tone of greater urgency. Colleagues have told me of senior researchers about to "throw in the towel" because of the loss of long-term grant support, and of bright and promising assistant professors at top universities unable to get funds to initiate their research. When I took office as President-Elect of the American Association for the Advancement of Science in February 1990, I decided to look more deeply into these reports to see if I could resolve the apparent paradox of continuing increases in federal research funding and growing dissatisfaction in academic laboratories.

With the help of the staff of the AAAS Directorate for Science and Policy Programs, I conducted an informal survey of key faculty in selected U.S. universities. This report, which I submit to the Board of the AAAS, describes the story as told by the nearly 250 scientists who wrote letters in response to my inquiry. Limited and informal as it was, the survey confirmed my expectations of trouble, but with a depth of despair and discouragement that I have not experienced in my forty years in science. I have included in the report my attempts to understand and interpret the situation, to evaluate the consequences, and to estimate what it might take to correct it.

Although the report may perhaps reveal indications of passion and advocacy, my concern is not for the unhappiness of my colleagues in science, much as I love and value them. My concern is for the future of science in the United States and for the profound cultural and economic benefits that science brings. My aim is to stimulate urgent discussion in the widest possible context. My hope is that this will lead to vigorous and appropriate follow-up activities.

In writing this report I am well aware of the hesitations of some colleagues, hesitations based on the desire not to appear self-serving, not to bring science down to the level of "just another interest group." However, if in fact U.S. science is at risk, then what course should we take? Is it not the obligation of societies like AAAS to bring the state of science to the attention of policymakers and the public that pays for and ultimately benefits from research? It is my opinion that the risks of appearing to be self-serving are far outweighed by the risks inherent in not making the case.

Please note that when I refer to academic research in this report I generally include both basic and applied research or, in the newer vernacular, fundamental and strategic research. Also, I recognize that I have focused narrowly on one sector of the research community and good science policy will require that any solution must also consider non-academic research as well as those issues outside of science which influence the health of the research universities.

Many people contributed to this report. Thanks are due to Richard S. Nicholson, AAAS Executive Officer; to Albert H. Teich, director of the AAAS Science and Policy Programs Directorate; and to Stephen D. Nelson, program director for science, technology and government, for their many contributions. The assistance of my physicist colleague James Trefil of George Mason University was invaluable in framing the issues described here. John Schoneboom and June Wiaz provided able research assistance at AAAS, Denise Graveline, head of the AAAS Office of Communications, provided important guidance and advice, and Patricia Morgan and her staff in the Office of Publications transformed the manuscript into the report that you see. Most of all, I owe a debt of gratitude to the nearly 250 academic researchers whose articulate and heartfelt responses are the basis for this report.

*Leon M. Lederman*
*University of Chicago*

*December 1990*

**[There were] three incidents where we had to stand by while competitors from abroad moved forward on research based on our ideas. . . . The history of the past decade is one of continued harassment over money, lost opportunities due to inadequate support, and a stifling of imagination due to money worries. If U.S. scientists must continue to stand by and watch as our best ideas are carried forward by groups from abroad, our nation cannot hope to escape a rapid decline.**
**—Professor of Physics, MIT**

**The effect . . . is devastating. Our senior faculty are demoralized and our junior faculty are jumping ship. Undergraduate and graduate students sense the despair and are turning away from science at a time when we need them most.**
**—Professor of Biology, U. of Illinois, Urbana**

**The funding situation is the worst I've seen in 25 years as a successful researcher.**
**—Professor of Chemistry, Yale**

Once upon a time American science sheltered an Einstein, went to the moon, and gave to the world the laser, the electronic computer, nylon, television, the cure for polio, and observations of our planet's location in an expanding universe. Today we are in the process, albeit unwittingly, of abandoning this leadership role. It is up to the President, the Congress, and the American people to decide whether this is really the road we want this country to travel.

America has lived and grown great through science and technology. From the founding of land grant universities and the flowering of agricultural research in the 19th century to the boom in microelectronics and information technology in the last two decades, we have hitched our economy to the best scientific research system we could develop and have prospered as a result. In this long-running success story, American universities have played a special role. University researchers have produced new knowledge to drive the economy and at the same time have trained successive generations of scientists and engineers to staff American industry.

But now, at a time when problems of international economic competition, environmental degradation, and quality of life demand the very best from our research community, new information assembled by the American Association for the Advancement of Science (AAAS) documents a deeply troubled mood among university researchers, even those who have been successful in pursuing research careers in our most prestigious institutions. This troubled mood is so pervasive that it raises serious questions about the very future of science in the United States.

The quotations that punctuate this report are drawn from an informal survey by the AAAS on the state of academic scientific research in the United States. Asked about their personal experiences with research funding, the respondents, who include some of the nation's most promising young academic scientists, portray an environment of slow, but steady erosion. One group can no longer train graduate students. Another sees its advances in technologies with millions of dollars of industrial potential dissipate for lack of a $100,000 laser. A third describes how it is abandoning innovative but risky research for more pedestrian projects for which funding is more certain.

The responses paint a picture of an academic research community beset by flagging morale, diminishing expectations, and constricting horizons. From one institution to the next, across demographic categories, across disciplines of research, the nation's scientists are sending a warning: Academic research in the United States is in serious trouble.

While it is difficult to make accurate predictions as to possible outcomes of the current situation, a major decline in research capability is certainly within the range of plausible projections. Indeed, given the current economic situation and budget climate, such a worst case scenario might be considered probable. In view of the close coupling we believe to hold between a vigorous and dynamic science and the economic and cultural well-being of the nation, this becomes a national problem.

Ironically, there is, among policymakers and the informed public, a general sense that American science is strong and healthy. Every year, we do well in the Nobel prize sweepstakes. Over the past decade federal funding for basic research has fared rather well in the budget battles, at least as compared to other areas of government spending.

Nevertheless, the AAAS survey provides a strong signal of trouble. It forces us to recognize that, however rosy the research funding picture may look from Washington, D.C., there are serious problems at the laboratory benches.

To understand the morale problems in the research community, it is necessary to look at the long-term picture, not just at how federal investment in R&D for this fiscal year compares to last or how R&D funding compares to transportation, agriculture, or other "domestic discretionary" programs. In this perspective, it is not hard to see the source of the problem. Despite recent growth, the level of federal support for basic and applied research in the universities in 1990, after correcting for inflation, is only slightly larger than it was in 1968, over twenty years ago.

In 1968 this level of funding was adequate. Indeed, 1968 was the peak year of a period that is considered the "golden age" of American science. Today, however, there are twice as many doctoral scientists in universities competing for those funds. Furthermore, in all areas of research the last decade's "easy" problems have been solved, and the cost of creating new understanding of nature has increased considerably. Finally, new regulatory requirements have added to overhead costs and reduced the funds available for the direct costs of research. Is it any wonder that morale among academic scientists is low?

Academic science has not arrived at its present state through a conscious decision by the Administration or Congress. No political leader has advocated starving science—indeed, most feel that they support it strongly. Presidents Reagan and Bush have both promised to double the size of the National Science Foundation's budget within five years, and Congress, almost every year, appropriates more for the National Institutes of Health than the Administration requests.

Scientists in the universities began to feel the pinch in the early 1970s, when the sustained growth of the previous decade came to an end and rapid inflation combined with constraints on the federal budget to produce a constant-dollar decline of more than 20 percent in federal funding for academic research. Warning signals arose at that time and eventually, to an extent, they were heeded. The trend in federal funding turned upward beginning in 1983. However, recent growth has been insufficient to compensate for the effects of the long drought that preceded it. Thus, in the view of those in the laboratories, there has been a gradual year-by-year erosion in the availability of funding and in the health of academic science over nearly two decades.

**As the referee reports indicate, I do excellent, important work and I write excellent proposals. When this is not enough to obtain funding, I wonder what else could be asked of me. . . . It is all very discouraging.**
**—Assistant Professor of Physics, U. of North Carolina, Chapel Hill**

**My students . . . find their current situation difficult and the prospects of trying to do research as faculty members positively frightening. They will avoid academic jobs. . . . There may be some rationale for allowing small-scale basic research to decline and for discouraging students from becoming academic researchers. If so, I haven't heard it.**
**—Professor of Physics, U. of Illinois**

**I suspect that if I were twenty years younger I would not choose an academic research career. Even now I find myself considering other options. I'm tired of writing "excellent" proposals that aren't funded.**
**—Professor of Chemistry, Duke**

**As funds for research disappear, I lose the ability to support students and to operate a laboratory. My current plans are to quit.**
**—Professor of Physics, U. of Texas**

# The Survey

> The future is quite bleak. Realistic analysis of the odds indicate the likelihood that, in the not too distant future, I will not obtain sustained funding. As my travel funds disappear and I can no longer have personal contact with my colleagues in the field, my reputation and the recognition factor, which are now essential to become the 1 in 10 who is funded, will dwindle. And when my start-up funds disappear, then I will not be able to keep a competitive lab going at all.
> —Professor of Physics, Carnegie-Mellon U.

> . . . I am dismayed by the great difficulties that so many of [the young faculty] encounter in obtaining grants. These are highly qualified young scientists, yet they are in much more dire straits, in the early stages of their careers, with regard to research funding than were their predecessors.
> —Professor of Physics, U. of Michigan

In May 1990, at my request, the staff of the American Association for the Advancement of Science initiated an inquiry to determine the professional "quality of life" as perceived by members of the academic research community. We sent letters to the chairs of the physics, chemistry, and biology departments at 50 universities—the 30 largest research-oriented universities, as determined by the amount of federal research funding they receive, and 20 additional universities, representing a range of less research-intensive institutions.

Each chair was asked to answer the letter personally and to forward it to a few faculty members, including at least one third- or fourth-year assistant professor in the department, and the youngest full professor. We wanted to hear from a range of researchers but especially from the "winners" in the game of academic science—the people with successful careers in the best-funded disciplines at prestigious institutions. If this group perceived itself to be in trouble, it would be a fair assumption that the great body of American scientists in other fields and initiatives could only be worse off.

Each respondent was asked to write a letter commenting on personal experiences in obtaining funding, the general availability of funding in the field, and how these factors would influence productivity and future plans. We made no pretense of drawing a scientific, random sample, nor did we attempt to cover all fields, types of institutions or geographic areas. Our purpose was not to generate statistics, but rather to collect anecdotes so that we might assess the prevailing mood among academic scientists. *(See Survey Questions, page 7.)*

We were not naive about what to expect. We recognize that no researcher is ever totally happy with his or her situation, and we expected a good deal of common, garden variety griping. Good scientists can always see more things to do, and those who are dissatisfied are more likely than others to take the time to respond to an inquiry such as ours. However, the emotional intensity of the letters and the depth of their pessimism was so far above these ordinary levels that we can only conclude that they register a mood of deep depression in the research community. And this depression is widespread, independent of institution, field and rank.

Nearly 250 letters, many of them long and detailed, were received. The overall tone of the letters, as exemplified by the excerpts that appear throughout this report, is one of deep concern, discouragement, frustration, and even despair and resignation. The traditional optimism of research scientists is being quenched. In its place are lowered expectations and a gloomy vision of the future.

The scientists write that obtaining funding occupies an increasing portion of their time. They describe growing regulatory burdens and increasing overhead costs. Many say they are embarrassed because they feel they are unable to serve as adequate role models for their graduate students. And, because the respondents are among the "best and the brightest," they are most keenly aware of the opportunities, the excitement and the ultimate benefits of their research—and the sharp contrast to the increasing difficulty in obtaining resources for it.

One scientist reports chagrin at the "superbright" post-doctoral student he cannot afford to hire. Another writes of discouragement at the two graduate students she has been forced to tell to go elsewhere. There is despair at seeing ones own ideas implemented by competitors abroad with the equipment one cannot afford. And overall, the *leitmotif* in the letters is of long hours spent writing (and reading) proposals and arguing and pleading with funding agency personnel.

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More than half the respondents in the top 30 institutions indicated that they are experiencing serious difficulties in research support or, at best, are treading water. An additional third reported that they were getting by for the moment, but saw problems ahead for their research. Even the minority of respondents who reported that they were managing pretty well themselves indicated they were affected by the depressed mood of their colleagues.

The distribution of responses from the less research-intensive universities was not much different. about 60 percent wrote that they are in trouble or are barely managing, an additional third reported they are coping but see problems on the horizon; while most of the remainder see colleagues in serious difficulties.

**I spend about 30 percent of my time writing proposals and progress reports . . . I love what I am doing but . . . morale, momentum, critical mass are all in grave danger.**
**—Professor of Chemistry, MIT**

**Nearly all our research groups have had to get by with at most level funding. The effect is devastating when continued over a number of years. Equipment is not replaced, students are not trained, and faculty grow discouraged. It is disheartening to see us lose our competitive edge at a time in which it could be especially important.**
**—Professor of Physics, U. of Washington**

**I expect that you will find . . . irreparable damage is being done to new young investigators starting up their first labs.**
**—Professor of Biology, U. of California, Berkeley**

# Survey Questions

Please write us a letter addressing each of the following issues:

1. The availability of research funding in your own area of research. Please comment on your own personal experience with the research funding system. Be as specific as possible.
2. The relative ease or difficulty of obtaining research grant funding currently as compared to past years (including the number of appropriate sources of funding for your research). Again, we are interested primarily in your own personal experience.
3. Your thoughts on how your recent experiences with research funding might influence your plans and expectations for the future.
4. Other factors significantly influencing your own productivity and ability to conduct research in your current setting.

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# Why is the Morale of American Scientists So Low?

The principal source of the morale problems the survey uncovered is no mystery. It appeared in letter after letter. It is essentially a lack of funding. For many scientists the difficulties of obtaining research support are beginning to overshadow the rewards of actually doing research. To understand why funding is so problematical, it is useful to review a few figures.

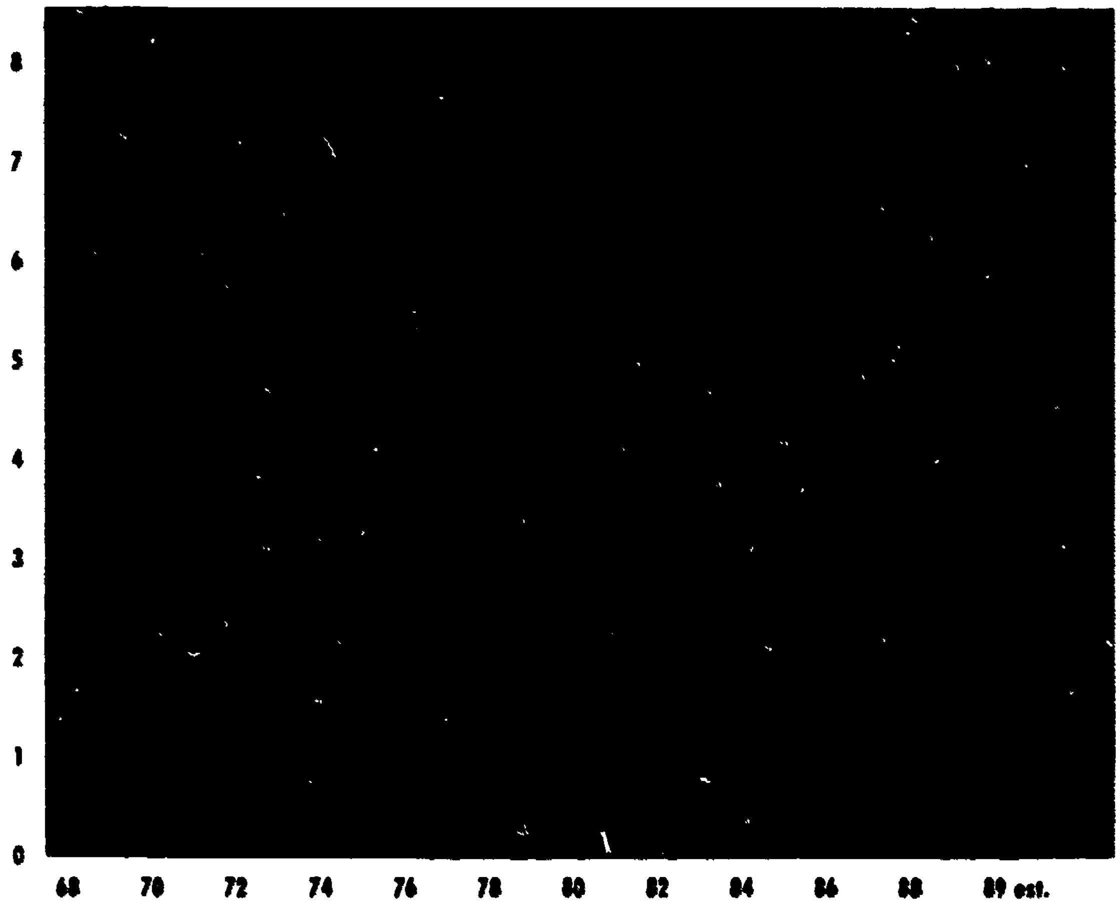
## Level Funding and a Growing Community

Since 1983, federal support for academic research in constant—that is, inflation-adjusted—dollars has grown by about 30 percent. However, as shown in Figure 1, this recent increase followed a long period of relatively flat funding which was itself preceded by a sharp drop between 1968 and 1974. Consequently, ***the amount of federal funding for basic plus applied research in universities in 1989 (expressed in constant dollars) is only 20 percent higher today than it was in 1968!***

At the same time, as shown in Figure 2, the number of doctoral scientists and engineers in colleges and universities has more than doubled. In other words, in 1990 there are over twice as many researchers competing for a pot of money not much bigger than it was in 1968.

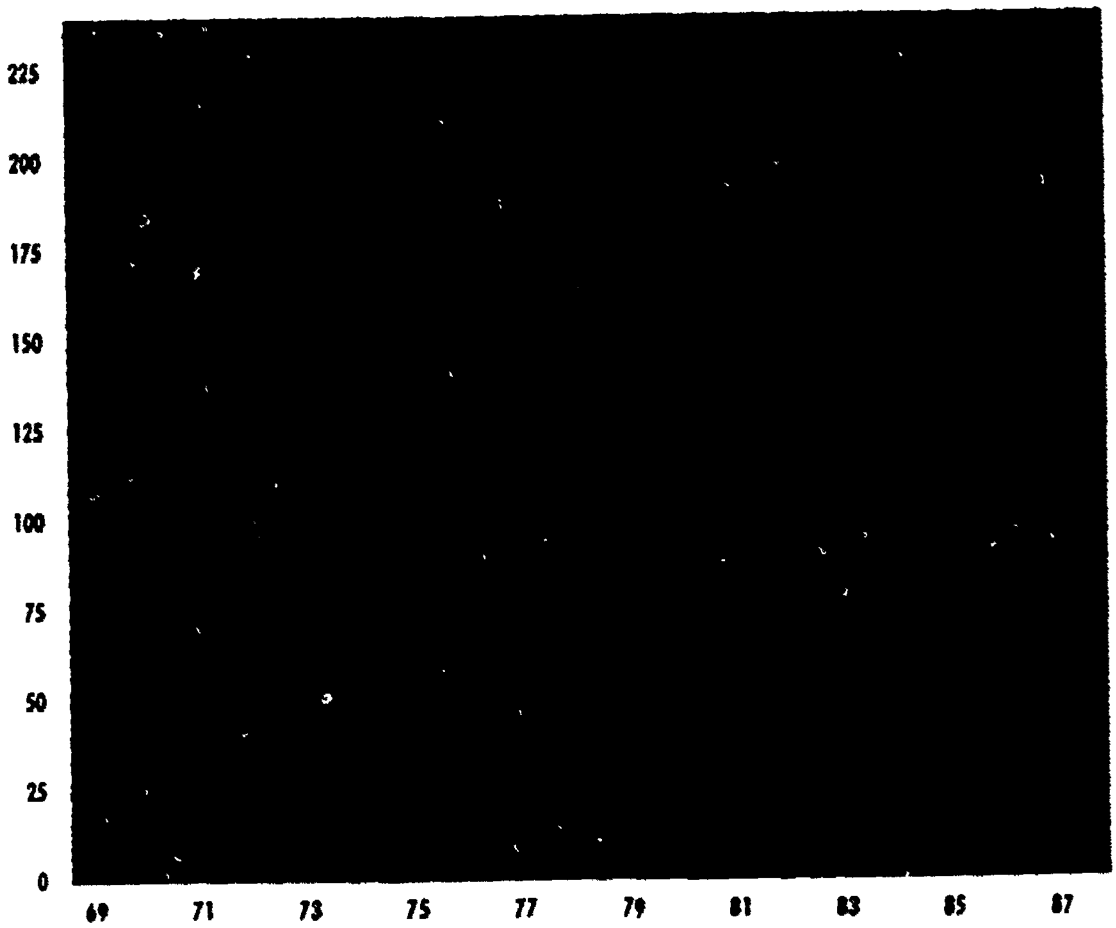
**Figure 1**

**Federal Expenditures for Basic and Applied Research at Colleges and Universities, 1968–89**
***(billions of dollars)***




*Source: National Science Foundation (Constant dollar conversions by AAAS, using OMB R&D deflator).*

**Figure 2** **Number of Doctoral Scientists and Engineers Employed By 4-Year Colleges and Universities, 1969–87**




*Source: National Science Foundation and AAAS estimate*

The growth in the academic research community, averaging about four percent per year, has gone largely to populate new and vital fields of research which, in 1968, were either non-existent or embryonic. This is simply an indication that it is in the nature of science to expand. Some examples of areas which have arisen to compete for funds with older, more established fields are molecular genetics, organometallic chemistry, materials science, chaos and complexity. Typically, older fields evolve into new areas of discovery. We cannot think of any field, thriving in the 1960s, that has disappeared in the past two decades.

## The Increased Cost of Doing Research

The phenomenon of level funding and a growing community of researchers in itself would clearly cause considerable hardship in the scientific community. The problem is compounded, however, by a number of other factors that, taken together, further restrict the results that can be obtained from each research dollar.

My failure to obtain a renewal . . . was a tremendous blow to my confidence. . . . I have since become more conservative in my research, rather than taking risks on potentially exciting areas.
—Assistant Professor of Biology, U. of California, Berkeley

. . . I feel pressure not to share information about exciting data . . . for fear that others, with larger labs, will be able to use this information to write a similar proposal.
—Assistant Professor of Biology, U. of Minnesota

## 1. Complexity

One factor is complexity—or what some observers have called "sophistication inflation." As our understanding of nature increases, the questions we need to answer become more complex. There is a corresponding increase in the sophistication (and cost) of the equipment needed to do research, both for small, "table top" experiments and large facilities such as telescopes and accelerators.

For example, a state-of-the-art dye laser cost about $19,000 in 1974. The corresponding state-of-the-art laser today costs $160,000. Even if we correct for inflation, a scientist who wishes to remain in the forefront of research in 1990 has to pay three times as much for this piece of equipment as he or she did fifteen years ago. Similarly, the cost of equipping a laboratory for a starting assistant professor in a university science department has increased by a factor of ten since 1968.

One might argue that there are countervailing trends. As the cost of certain technologies decreases, the cost of doing science should go down as well. Ordinary hand calculators, for example, once cost several hundred dollars, but now cost only a fraction of that sum. While this cost reduction is real, in practice it is completely swamped by the increased demands for computation. Although the cost *per arithmetic operation* has gone down dramatically since 1968, the increased need for computing power has made computer costs a major portion of today's science budget. Similarly, the unit cost of building an accelerator has dropped from $1,000 per MeV at Fermilab (in 1970) to $100 per MeV at the SSC, but the energy required to do meaningful research in high energy physics has gone up so much that the total cost of the required accelerator is much higher today than it was in 1968.

These are not just examples of researchers trying to keep up with the Joneses—one can no more do 1990s research with 1974 equipment than one can build a modern superhighway with pick-and-shovel labor. The complexity factor is a direct cost imposed on research by increasing sophistication in science.

## 2. Increasing Costs of Regulation

The cost of regulation is a second factor. In many fields, particularly in the life sciences, increased regulation absorbs significant funds and research time. Requiring researchers to comply with guidelines such as those concerning animal care, human subjects, low level radioactive waste and hazardous substances is important and certainly justifiable, but it must be recognized that the costs of complying with these regulations reduce the amount of research that can be done for a given amount of money.

## 3. Increased Overhead

A third factor is institutional overhead. According to the National Science Foundation, indirect costs at universities (including administration, maintenance of buildings, utilities, etc.) have risen from 16 percent of the national academic R&D budget in 1966 to about 28 percent in 1986. Charges equivalent to 70 percent of salaries are not unusual today. In the minds of many faculty members, overhead amounts to a tax on research. Obviously, it is a legitimate component of the cost of doing research and its recovery in research grants is essential to the survival of the universities. But, as is the case with increased regulation, the absorption of a growing share of research money by overhead means that less money is available to the laboratory scientist for the direct costs of the research.

# Impacts of the Funding Situation

Let us turn now from the sources of the problem to its impacts. The letters suggest that—apart from just being a source of frustration to academic scientists—the squeeze on research funding is likely to have a number of more subtle adverse consequences for research and for the nation.

With more scientists competing for what is essentially a fixed pot of money, the percentage of grant applications funded by NSF and NIH has dropped precipitously. As *Science* magazine has reported, success rates in some fields are down to the neighborhood of 10–15 percent. Scientists, particularly young scientists, report spending more and more of their time chasing fewer and fewer dollars. While the average grant size has increased somewhat at NIH, the typical NSF grant is, in constant dollars, considerably smaller in 1990 than it was in the early 1980s.

The problem is more serious than average grant size or proposal success rates, however. The letters reveal potentially important changes in the way scientists as individuals pursue their craft. As a consequence of the increasingly difficult search for funding, academic scientists are less willing to take chances on high risk areas with potentially big payoffs. Instead, they prefer to play it safe, sticking to research in which an end product is assured, or worse, working in fields that they believe are favored by funding agency officials. These scientists are also increasingly viewing their fellows as competitors, rather than colleagues, leading to an increasingly corrosive atmosphere. The manifestations of this attitude range from a reluctance to share new results with other scientists to public bickering about relative priorities in funding different fields.

**Every time you write a proposal for a renewal of your grant, you are playing Russian roulette with people's lives. You soon find that your chief responsibility is no longer to do science at all; it is to feed your graduate students' children.**
**—Professor of Physics, Caltech**

**We are tending to do "safer" projects, avoiding the high risk, but high payoff projects. In the present climate we cannot afford to have experiments not work. . . . Undergraduates, graduate students and postdocs constantly ask about the benefits of pursuing an academic career when funding is so tight.**
**—Assistant Professor of Biology, Carnegie Mellon U.**

**The shortage of research funds has led to higher competition. There is now much more pressure to produce in order to secure funding. Consequently, in selecting research problems, we have to put emphasis on the less uncertain ones. The more fascinating but risky problems are being shelved for the time being.**
**—Professor of Physics, U. of California, Berkeley**

While the current loss of productive groups is serious, even more disturbing is the negative influence the present difficulties are having on the next generation. On a recent visit to MIT I had an informal lunch with about twenty graduate students in organic chemistry and asked how many of them were going into academic science. One person raised his hand and he was returning to a small liberal arts college where he had been a student. This group agreed that their lack of interest in university level positions is their perception that the challenge of gaining funding is now dominant over the challenge of the science.
—Professor of Chemistry, U. of Illinois

I am so heavily invested on a personal level in basic research that I cannot imagine changing my own career direction even if the present funding situation persists. However, I am finding it harder and harder to recommend this career to the many bright undergraduate students who regularly seek my advice in career opportunities in basic research.
—Assistant Professor of Biology, U. of California, Berkeley

But there are other effects of the funding situation that are evident in the letters—effects that will not be felt for some time, but that are potentially much more damaging. Over and over again the respondents reported that they are cutting back on the number of students they are training, and that students now in the laboratories are opting out of research careers. It is not too hard to imagine the thoughts in the mind of a graduate student who watches as a professor spends a third of his or her time searching for funds to keep a laboratory going.

I will wait a while to take on more students because I will not have support for them.
—Professor of Ecology, U. of Minnesota

In the longer term, the shortage of funds . . . will probably cause me to take on fewer graduate students.
—Professor of Physics, Harvard

The professor-graduate student relationship is one of the most important ingredients of a scientist's education and is widely regarded as a key to the success of U.S. science. One of the prime tasks of the faculty member is to serve as a role model for the student—to say, in effect, "This is what a scientist is like." The relationship entails obligations on both sides of course, but the professor usually assumes a responsibility for seeing that his or her students are supported during their studies and placed in appropriate jobs when they finish.

In one letter after another, those responding to the survey expressed concern that they could not fulfill the obligations they had assumed when they took on students—that they could not serve as successful role models for the next generation of scientists. This breakdown of an important part of the traditional education is another serious and unexpected consequence of the funding situation. And the mood will inevitably be communicated to undergraduates in an ever-widening ripple effect.

> While the difficulty in obtaining research funding has taken its toll of time and energy, I plan to continue in this position and with basic research. However, it is clear that my first three postdoctoral research fellows (now on the job market) and other postdoctoral fellows at Caltech who I know, have a quite different perspective from that which I had a few years ago when I conducted my job search: they are extremely pessimistic about obtaining any funds to run their labs and are considering quite different sorts of jobs.
> --Assistant Professor of Biology, Caltech

> The difficulty of acquiring research funding leaves me with a grim impression of my professional future. I love research too much to contemplate leaving this career, at least at this point, but I often wonder about the level at which I will be able to pursue my professional interests in the coming years. I am certain that my anxieties on this subject, and those of my colleagues, have a negative effect on the impressions of scientific careers formed by the undergraduates and graduates with whom we are in constant contact.
> —Assistant Professor of Chemistry, U. of Wisconsin

> Perhaps the most serious consequence of diminishing prospects for funding is the effect it has in discouraging graduate students and post-docs from pursuing scientific careers. As a junior faculty member, I remain in close contact with colleagues from my days as a student and post-doc, but several of the best of these individuals will not show up in your survey—they have already chosen to leave science.
> —Assistant Professor of Biology, U. of Pennsylvania

The responses to the AAAS survey suggest that in the coming years we can expect even fewer students to enter careers in science than do so now. It is ironic that as the enormous efforts to improve science and mathematics education that were initiated in the 1980s begin to bear fruit, the scientific infrastructure they were designed to support is being progressively eroded.

# Why Keep Science Healthy?

How much does all of this matter to the nation-at-large? Given that low morale is a problem for the science community, why should the rest of the nation care? Scientists are, after all, a privileged class far better off than many in our society, and besides, there are already more crises around today than our overloaded national consciousness can handle.

The answer is, of course, that science pays. It is impossible to imagine modern society without the fruits of 400 years of scientific research. An extensive literature documents the returns to the economy generated by expenditures on science and technology. One has only to examine the ingredients of our GNP to see that a large fraction is derived from the results of the scientific research of the past 60 years or so.

Economists have estimated that for every dollar spent on the Apollo program in the 1960s, seven dollars of economic activity was generated in the American economy. More recently, economist Edwin Mansfield of the University of Pennsylvania studied the rate of return on investments in academic research. His work covered 76 major firms in seven industries: information processing, drugs, metals, electricity, chemicals, instruments, and oil. His assumptions are conservative but his result is startling: the annual social rate of return on investments in academic research is no less than 28 percent.

The tasks which are faced by American science and technology today are crucial as never before to the well being of our nation. They include:

- providing the basis for new industry to enhance the quality of life of our citizens, while extending those benefits to regions and groups that have not yet shared in them,
- improving the general health of the population while containing the costs of medical care,
- understanding the complex circumstances surrounding ecological and environmental issues and providing guidance to policymakers in these areas,
- developing alternate sources of energy and substitutes for scarce natural resources; and
- enhancing our culture by expanding our understanding of the universe and humanity's place in it.

To carry out these daunting tasks in an ever more competitive world, we will need more scientists and engineers. Yet demographic projections— such as those cited by Richard Atkinson in his 1990 Presidential Address to the AAAS—tell us that we are falling short of producing the required number of Ph.D. scientists and engineers by about 10,000 each year. Huge deficits in the number of technically trained personnel (estimated by some at up to 700,000) are expected in the first decade of the 21st century.

I am aware that such projections have large uncertainties, but I should also point out that they may be underestimated because they fail to take account of the new demands that will be placed on science and technology by environmental problems, energy and natural resources, and the needs of developing nations. Given that graduate education depends so strongly on research funding, the finding that faculty members are cutting back on the number of students they train means that the current funding situation can only exacerbate future problems in human resources for science and technology.

**I'm rather bewildered. I believe that I'm one of the best young theorists in the country. Without a doubt, I've had by far the most successful group of graduate students in my field. [Yet my] NSF single-investigator funding is being cut from four students to none. In the past two years, my efforts to avert this disaster have been fruitless. For obvious reasons, I'm forced to change my style of research. In the next two years I'm shifting a large part of my efforts to workstation software development, for which there is support from private industry.**
**—Associate Professor of Physics, Cornell**

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# How Much Research Do We Need?

I contend that the United States is underinvesting in research. The result is a drastic decline in the morale of even the best academic researchers. I believe that if U.S. science is going to have a chance to help the nation meet the challenges it faces, we must create a new environment for research. The ideal environment is one in which any talented scientist can obtain research funding if he or she has a good idea and can meet the burden of reasonable review and resistance.

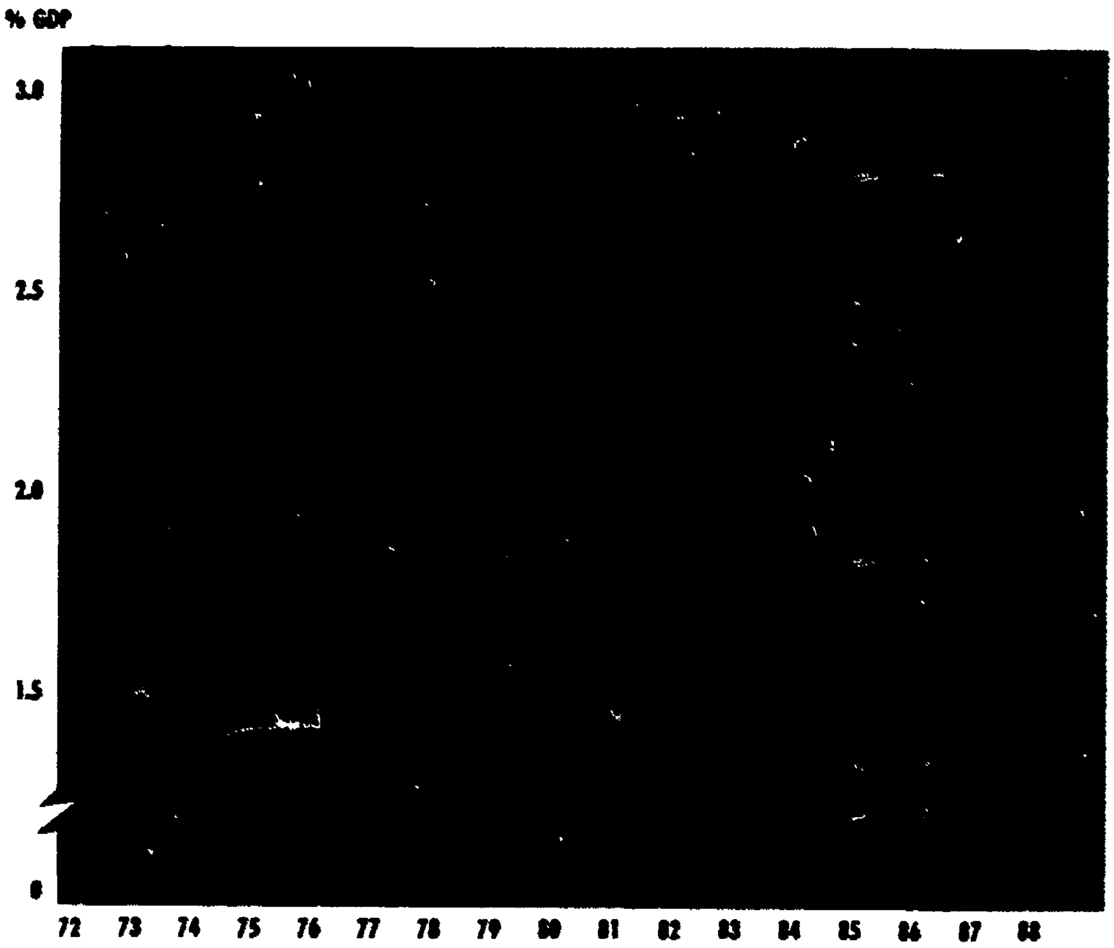
Since a portion of the current funding crisis arises from the increase in the number of scientists, some might argue that it would make sense to practice a kind of "scientific birth control"—to limit the number of scientists plying their trade, in order to fund the remainder adequately. Is such an approach reasonable? The answer to this question depends on how much scientific work one feels needs to be done.

There are two ways to approach the question. One is to look at nations that are doing a good job economically—nations that seem to be doing well in international economic competition. The other is to look at what society requires of science in a broader sense and assess the adequacy of any proposed system to meet those needs.

The period from shortly after World War II to 1968 has often been referred to as the "golden age" of American science. It was heralded by a report to the President in 1945 by Vannevar Bush, entitled *Science, the Endless Frontier.* The "golden age" was characterized in effect by just the conditions I now advocate: a funding level that permitted full play to the creativity and imagination of scientists. As Figure 3 indicates, we are still benefiting from the fruits of that era. I believe that the creation of a new golden age is not only affordable, but holds vast potential for benefits to the nation.

**Figure 3** **Partial list of Technologies Developed since World War II that are at the Forefront of Economic Growth.**

**Figure 4** **Non-Defense R&D Expenditure as a Percentage of Gross Domestic Product**




*Source: Council on Competitiveness and National Science Foundation*

The world of the 1990s is a far cry from 1968. In the late 1960s, the United States was the undisputed leader in world science. Our basic research establishment was turning out results that would fuel the boom in Silicon Valley and establish new centers of information technology on the outskirts of our major cities. Medical techniques we now consider routine—CAT scans, for example, or magnetic resonance imaging—were still gleams in the eye of basic researchers or in the early stages of development. The future was bright and there seemed to be no limits to our dreams.

Today, after 20 years of gradual attrition, the effects of which are vividly documented in the AAAS survey, the future no longer looks so bright. The United States can no longer claim undisputed leadership in world science. Western Europe and Japan both have thriving scientific establishments, offering both collaboration and competition to their American colleagues. Figure 4 shows funding for nondefense R&D as a fraction of GNP in several countries including the United States. The story is all too clear. Our own expenditures have remained almost constant during the past two decades, while those of Western Europe and Japan have grown. Measured

The country loses by not taking advantage of creative genius while the opportunity exists.
—Professor of Physics, U. of Washington

We invented the technology [of ferroelectric crystals], but who do you think has developed it almost to the point of commercialization? Yes, of course, Japan.
—Associate Professor of Physics, U. of Colorado

We now watch as the former RCA Lab in New Jersey is sold into a contract house as Nippon Electric opens a first rate research lab one mile away.
—Professor of Physics, Carnegie-Mellon U.

against our most successful international competitors, then, the current level of research funding in the United States is evidently inadequate.

Looking toward the future, Figure 5 lists some "emerging technologies" identified by the Department of Commerce, which are projected to have a total economic activity of about $1 trillion by the year 2000. The connection of these technologies with mastery in the relevant fields of science and engineering should be obvious. The question the nation must ask of its policymakers is: What fraction of this huge sum will belong to the United States?

The second part of the answer involves the huge tasks and enormous opportunities facing science and science-based technology today. These have been outlined above, and include improving the nation's health, economy, and quality of life and tackling the complex of environmental, energy and resource problems that loom ahead. Whether we will be able to meet these demands and exploit these opportunities depends to a large extent on how well we will be able to recruit young people into science and engineering studies. This has been recognized by the President, the nation's governors, and by the Congress.

Support for science education, with recent emphasis on the elementary and secondary levels, has been increased impressively. States and communities across the nation are instituting reforms in an escalating effort to catch up to our foreign competitors whose children do so much better in international assessments. A major part (by no means the entire part) of this effort is to increase the flow of American children into science, mathematics and technology. Without this effort in science education, our research capability both in and out of academia would increasingly depend on immigrants for whom there is increasingly vigorous world-wide competition. However, if we ignore the health of the academic research system, this entire effort will surely be compromised.

I would argue that it is unwise to attempt to solve the present crisis by reducing the number of scientists at our universities. Not only would this reduce our ability to solve our nation's problems in the short term, but, even worse, it could start a downward spiral in the size and quality of the U.S. academic research system that would be difficult, if not impossible, to reverse.

**Figure 5** **Critical Technologies**

*Source: U.S. Department of Commerce.*

# An End to the Frontier?

The warning in the AAAS survey is clear. American science shows signs of extreme stress. Morale is declining, students are turning away from science, and American leadership in scientific research, as measured by published papers and Nobel prizes, is threatening to go the way of the automotive, tire, machine tool, and consumer electronics industries.*

The implications of the loss of such leadership are immense. Just as the "brain drain" drew talented scientists from Europe and the Third World to the United States in the 1950s and 1960s, so too will some American scientists (and potential immigrants) follow the frontiers of their fields to Europe, the Pacific Rim, or wherever they might be in the future. The pipeline of new research that has nourished our high-tech industry will dry up, crippling our ability to compete in a world where science and technology play an ever more important role.

We can already see ominous signs in economic trends. In 1986, for the first time in history, the United States imported more high-tech manufactured products than it exported. Residents of foreign countries now receive almost half of the patents granted by the U.S. Patent Office. And the three corporations registering the most U.S. patents last year were Canon, Toshiba and Hitachi.

Finally, we should not neglect to mention the more subtle, less quantifiable but nonetheless profound influence that science has upon society. We are a great nation which must value the culture that the success of science engenders. This success permeates society, generates self-confidence, inspires our youth, creates a sense of endless frontiers of the human mind and of human aspirations which would otherwise become increasingly confined in an ever-shrinking world. The loss of this scientific and technological exuberance would be another heavy price to pay, perhaps even the greatest penalty in the long run, for the decline of the research system.

The full effects of the impoverishment of basic research will not be felt next year or the year after. We have been living on our accumulated scientific capital for a while, and we will probably be able to do so for a while longer. But if we persist on this course, we can expect to see America's position in the world gradually weaken. We will watch as our technology-based products become less and less competitive in world markets. By then, of course, it will be too late.

It is the long-term nature of the enterprise that makes the issue so dangerous. Once we begin to weaken, there are many feedback forces that tend to accelerate the decline. The best people move on to other activities. Students are no longer attracted. The stream of immigrants diminishes. The essential influx of young investigators dries up. Within the range of possible outcomes are both acceptable and unacceptable consequences. Yet to wait rather than take action now is to invite a situation that will be difficult and very time-consuming to reverse.

*It is worth noting that the bulk of U.S. Nobel prizes in recent years have been based on work done before 19[illegible]

# Conclusions and Recommendations

A large-scale anecdotal survey of some of the most capable and productive U.S. academic scientists has been carried out. The results are a clear warning that all is far from well in the laboratories of our research universities. The depressed state of the academic scientific community is attributed to a failure of our system of science funding to recognize and maintain the essential needs of a healthy infrastructure.

Science funding has increased steadily in the past several years, yet it is apparent that current levels are far below what is required for healthy, even lean, science. Perhaps this may give some policymakers a sense of frustration at the "ungrateful and insatiable scientists." Yet we are not alone in seeing this problem. Warnings have been creeping up everywhere. Almost five years ago, the Packard-Bromley report documented an obsolescence of university research equipment and evaluated the cost of renovation at $10 billion. Since becoming the President's Science Advisor in 1989, Allan Bromley has continued to speak out about underinvestment in research, as has Frank Press, the President of the National Academy of Sciences. There is an emerging consensus among science policy leaders that we are not making the long-term investment in research required to restore our economic and scientific leadership.

The United States today finds itself slipping in its ability to compete with dynamic societies abroad. The new Europe, Japan and the Pacific Rim nations are increasing their investment in research, having already surpassed us in the various activities needed to convert research results to economic benefit. It is up to us as a nation to decide whether the U.S. will remain a major player in world science and science-based technology or whether we will continue to slide.

One could argue that since the results of basic research are globally available, we need maintain only the ability to read the scientific literature in order to compete in technology. However, the current large increases in European and Japanese investments in basic research and the dignity of a great nation argue against this. Looming over and above the economic factors are the complex issues of ecology, energy, and natural resources in a world which must, in the next century, see vast development in the South. Such development cannot be sustained without research to create the technologies which are required to reduce the uncertainties in environmental predictions and to solve the energy-ecology problem.

What would it take to relieve the acute problems in academic research and restore U.S. science to its pre-1968 excellence? Let us consider this question independently of "practical" constraints dictated by current events. My analysis of the complexity factor, the growth of new areas, and the increasing costs of research indicate that we should be spending at least twice as much as we were in 1968 (in constant dollars) if we are to approach the conditions of the golden age. Indications from NSF, NIH and DOE tend to confirm the pressure for a doubling of the current level of funding for academic science, which amounts to about $10 billion a year. This huge sum could, I believe, be effectively deployed in two or three fiscal years.

Beyond this, in future years, I would argue that the growth of four percent per year in the number of academic scientists and the complexity factor growth estimate of five percent per year imply that a sustained flourishing of academic research requires annual real growth of eight to ten percent. It has been estimated that this kind of growth would move the proposal success rate in NSF and NIH closer to 50 percent from the present much lower levels. Such an increment may sound substantial in our current climate, but as the economy responds, academic research would remain only a tiny fraction of total federal spending for many decades. Furthermore, even with such increases, it would be a decade or two before our level of nondefense research expenditure proportional to GNP would equal the 1989 levels of Japan or West Germany.

Can we afford this kind of money? In 1980, the President of the United States convinced the Congress and the American people that we must double the defense budget to $300 billion a year. This was done and somehow the nation was able to absorb the cost. In 1990, the threat to the security of the nation lies in an endangered scientific infrastructure. The required sums are substantially smaller. The danger is long term but the longer we wait, the more difficult will be the remediation.

Let us for the moment accept that this investment in science funding is in fact required. How shall we proceed? In the present climate of deficits and escalating demands on the federal budget, there arises a fundamental policy dilemma. The federal deficit, the savings and loan bailout, the Persian Gulf crisis are real and immediate. The crisis of American science, no matter how serious, is a long-term affair—it is for our children and our children's children. Given the characteristic short-term philosophy that has dominated American policy for the past several decades, we have no illusions as to the probable fate of our recommendation.

Nevertheless, strong efforts must be made immediately to strengthen federal funding for research. Appropriations of NSF, NIH, DOE, and other federal agencies that support academic research should be increased sharply as soon as possible. Beyond this, however, in order to alleviate the dilemma of short-term priorities and long-term problems, I recommend that serious efforts be made to find innovative ways to fund academic research on a national scale *outside* of the regular federal budget. One approach might be to establish a trust fund supported by special taxes on high technology consumer products that benefit from basic research. Another possibility is to form a partnership between the government and the investment community. One can contemplate government bonds, designated for research, with interest keyed to the returns on that research.

To investigate such possibilities and others, I am recommending that a Commission be established consisting of representatives from the Executive and Legislative Branches of the federal government, industry, the financial community, and the academic community. AAAS should take the initiative in promoting and organizing such a Commission.

In addition to examining funding mechanisms, the Commission could also look at ways of improving the efficiency and the strategic planning of research funding and ways of assuring that academic research serves the nation most effectively. An assortment of problems we have not been able to address in this report cry for attention. I am, of course, aware that academic science is not the only component of higher education, and that the health of academia as a whole must be addressed. University issues such as graduate student support, the effect of new tax policies on philanthropy, student stipends and the ability of institutions to raise capital should be examined where relevant to the research environment. The contentious issues of balance between big science projects and individual investigator research, and the role of centers versus project grants also demand attention. It seems entirely appropriate for AAAS, in collaboration with other organizations, to foster creation of a Commission to make a broad study of what it will take to make U.S. science whole again and to design an appropriate strategy. I stress that the time is short and the issues are urgent.

In concentrating on funding, I am aware that there is much we must do in those crucial activities which connect research results to economic utility. These involve subtleties of technology transfer, tax laws, marketing and other functions which the academic community has traditionally ignored, but with which it must learn to interface more gracefully. The Commission should include this important area in its charge.

Apart from establishing the Commission, the AAAS Board should make the communication of the precarious state of U.S. science a high priority. The best efforts of the Association must be applied to create an environment where the health of American science is widely perceived to be essential to the future of our nation. To that end, AAAS must provide leadership in rallying all segments of our society to the cause of rescuing U.S. science.

I conclude this report with an excerpt from Vannevar Bush's landmark report, *Science, the Endless Frontier,* which in 1945, set the nation on a course that has had profound consequences for its well being:

> *It has been basic United States policy that Government should foster the opening of new frontiers. It opened the seas to clipper ships and furnished land for pioneers. Although these frontiers have more or less disappeared, the frontier of science remains. It is in keeping with the American tradition—one which has made the United States great—that new frontiers shall be made accessible for development by all American citizens.*
>
> *Moreover, since health, well-being, and security are proper concerns of Government, scientific progress is, and must be, of vital interest to Government. Without scientific progress the national health would deteriorate; without scientific progress we could not hope for improvement in our standard of living or for an increased number of jobs for our citizens; and without scientific progress we could not have maintained our liberties against tyranny.*

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