

# 28 The Role of the United States in 21<sup>st</sup> Century S&T: Leader, Viable Competitor, or Follower?

**Mary L. Good**

In the late 1800s, the scientific community, especially physicists, thought it was quite possible that the great ideas for the advancement of science were behind them. Although radioactivity had been discovered, and a rudimentary understanding of atomic properties was possible, chemists and physicists were primarily measurement specialists. Sir Ernest Rutherford, Britain's best-known physicist of the time, is quoted as saying, "... physics will be relegated to increasing the decimal points in our measurements." This remark is used as a great example of misguided predictions. The triumph of Charles Darwin over the tightly controlled British educational establishment and his view of the natural order of living things had moved observational biology to the forefront of scientific thought. However, the end-of-the-century tools available to science meant that measurement improvement and theories based on the correlation of observational data were actually state-of-the-art.

This end-of-the-century nostalgia for new ideas was short-lived. Max Planck's obscure paper on quantum physics in 1900, and Albert Einstein's theory of relativity published in 1904, changed all of these projections and provided the initial foresight into the science of the 20<sup>th</sup> century, which has been labeled by many as the "Century of Physics." One can argue, however, that it was the "Century of Physical Sciences,

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Mathematics, and Engineering,” with the last quarter of the century seeing the phenomenal rise in the biological sciences, especially the health-related sciences.

The fundamental new insights gained from the exploration of quantum theory dominated the first quarter of the century and forever transformed how we think about and describe our physical and biological universe. It is important to remember that American science was a minimal force in this effort. European scientists and scientific institutions provided the intellectual leadership to develop the underpinnings of today’s scientific thought.

During the first half of the 20<sup>th</sup> century, American science was rather pragmatic because of the rise of the industrial revolution and America’s isolation during the First World War. These factors drove the need for technologists who could adapt materials and processes to improve industrial productivity while also creating new products for industry, consumers, and the military. Engineering flourished in this environment, building infrastructures and designing industrial plants and processes.

The rise of the research university was yet to come. Most educational institutions focused on undergraduate education. Those who did undertake scientific research depended on foundations, personal benefactors, and other disparate sources for support. It was clearly the era of “sealing wax and string” in physics and industry support in chemistry. Dr. Roger Adams, chair of the Chemistry Department at the University of Illinois and one of the foremost American organic chemists, supported the department and its graduate students by running a company that prepared organic chemicals on demand. This anecdote suggests that close university-industry interaction is not strictly a 1990s phenomenon.

This state of affairs for American science and scientists changed dramatically with the onset of World War II. First, American science was infused with outstanding talent from Europe because of the political issues of the day. Second, as war became imminent, the government recognized that developing technology for the war effort would have to be a very high priority.

The harnessing of the scientific and engineering community was a national success story. The community did provide the technology needed for the Allied forces to prevail. It was able to respond to the grand challenges presented by the Manhattan Project. It designed and built the U.S. ocean fleet and superior aircraft squadrons in record time. The physical sciences and engineering came of age in this period, and group

effort translated research findings into useful concepts very rapidly. The value of biology, particularly as it relates to the development of antibiotics and other drugs, also became widely understood.

Before World War II, the United States did not have anything at the federal level that might be called a science and technology policy aside from the areas of agriculture, standards, and aeronautics. The U.S. Department of Agriculture's experimental stations and regional research laboratories provided the scientific background and technical support that enabled U.S. farmers to feed the nation with a small labor force, and eventually to become major exporters. The Bureau of Standards was created in 1901, to provide standard weights and measures and metrology development. The U.S. government had, from time to time, contracted for scientific research or technical assistance to help solve a specific problem. It had also provided support for the introduction of infrastructure technologies such as the telegraph. However, there was no government agency devoted to research and development and no programs for science support. Thus, the mobilization of the science and engineering community during the war was the beginning of a science policy that matured after the war.

As has been discussed in many books and reports, the establishment of such policy was accompanied by competition among the organizations created during the war, political infighting, and a misunderstanding by the scientific elite of how a democracy works during peacetime. In the early 1950s, the country found itself with multiple sources for research funding for both intramural and extramural work, instead of a central organization for science managed by scientists. Agencies such as the Atomic Energy Commission, the Naval Research Laboratory, and other defense organizations vied for federal funds with the fledgling National Institutes of Health (NIH) and the National Science Foundation (NSF).

Vannevar Bush's idea of a single science agency that would fund the proposed research of university scientists and that would require peer assessment of this research was reduced to the NSF and NIH. Both of these organizations initially had quite small budgets and were focused primarily on infrastructure support and training. Today, the National Science Foundation, which was to provide for self-initiated research in all fields of science except the health sciences, still receives less funding than the research budget of the Department of Energy (DOE). In fact, DOE still funds much of the research in physics, materials science, and other physical sciences.

The advent of Sputnik caused the nation to reevaluate its science and math education programs and to create a new agency to respond to the space challenge. The National Aeronautics and Space Administration (NASA) was organized to “put a man on the moon” and display the nation’s technical superiority. While the government did not assign this task to NSF, the Foundation did benefit from the initiative in its education programs and other basic sciences, especially the physical sciences. However, NASA was a major supporter of engineering because the moon project demanded innovative design and precision engineering, not new science.

Thus, the “science policy” of the U.S. federal government has always been to use science and technology to solve immediate problems or to provide a broad base of knowledge that can be defined as programmatically useful for society’s needs. These needs include basic research in the health sciences, materials, instrumentation, environmental chemistry and biology, energy sources, and many other fields. It is true that NSF supports some very basic research for which there is no immediate practical relevance. However, most of the country’s research dollars are appropriated for specific programs that the appropriators believe will benefit the country in some socially positive way.

There has been a great deal written about the “social contract” for science. A new book by David Guston provides an in-depth discussion of the “social contract” as science policy and discusses why we need a new way of thinking about science policy for the new century.<sup>1</sup> The summer 2000 edition of *Issues in Science and Technology* gives a shorter version of Guston’s ideas.<sup>2</sup> It states that “the essential elements of postwar science policy were: the unique partnership between the federal government and universities for the support of basic research; the integrity of scientists as the recipients of federal largesse; the rapid translation of research results into economic and other benefits; and the institutional and conceptual separation between politics and science.”

These precepts were the foundation for the research universities in the United States. They resulted in the country tying its development of an advanced scientific and technical work force with the funding of research for universities. The United States is unique in that education and research have been so closely coupled. In the first two decades after World War II this mode held fairly well. Research, scientific infrastructure, and traineeships were funded to universities and principal investors via peer review with minimal direct oversight by the agencies.

Over time this model has changed. Now, even in the basic research areas, the government “procures” research and demands accountability and oversight. Thus, Guston believes that the old “social contract” is obsolete and should be replaced by a policy based on “collaborative assurance” where specific boundary organizations would help set priorities, conduct jointly sponsored research, and assess the quality of the program.

My own view is that the “social contract” was flawed from the beginning because the separation between federally supported science and politics is not possible in a democracy where discretionary spending is controlled by the political process. The delay in the legislation that set up NSF was certainly politically motivated. Senator Harley M. Kilgore of West Virginia wanted federal funding distributed at least somewhat geographically. Vannevar Bush wanted peer review and quality control by scientists themselves, which meant that the bulk of the funding would go to elite institutions where scientists of stature were clustered.

Thus, it would seem that the policy of the scientific community should be one that defines the scientific enterprise in terms the public and the policymakers can appreciate. It should also provide the keepers of the public purse with reasoned arguments for the priority or competitive position of science funding with respect to other expenditures that clearly support the public good. The emerging discussion among policy people on “Jeffersonian science” is an attempt to make this connection. A paper by Gerald Holton and Gerhard Sonnert in the fall 1999 edition of *Issues in Science and Technology*<sup>3</sup> and a fall 2000 conference<sup>4</sup> organized by Lewis Branscomb at the American Association for the Advancement of Science (AAAS) are representative of these ideas. (See Chapter 35 in this volume.) They would create a research policy that emphasizes research categories representing critical social needs as umbrellas for basic research.

While the scientific community has a responsibility to appropriately position their funding priorities, the federal government has a duty to formulate a policy that allows government agencies and the public, via Congress, to plan for a sustained science and technology effort that supports the changing needs of this new century. The government should seek to provide a much broader group of technically trained and scientifically educated people and a science and technology pool that sustains our national security, our economic growth, our public health, and our continuous need to better understand and better protect our physical and biological universe. I will return to these policy questions after a brief

review of where we are today, including both our advantages and our disadvantages.

Because of, or in spite of, the somewhat muddled science and technology policy of the last 50 years, the United States has led the world in scientific development and has created an environment where science flourishes and technological innovation has spawned a “new economy.” The science of physics and chemistry have provided the foundation for a century of new products and new processes that have changed the way we live and work in ways totally unforeseen. They have provided the basic discoveries that led to the major breakthroughs in biology through better instrumentation, molecular separation processes, and automated experimentation. One has only to review the results from electron microscopes, nuclear magnetic resonance machines, automated sequencing devices, and many other widely used tools to see the profound effect on biology. Biology has progressed from observational studies to the ability to understand living systems at the molecular level and to create totally new materials to fight disease. Mathematicians, in addition to their contributions to fundamental theories of the unity of science, have moved number theory from an abstract idea to the language of computers and have provided the underlying connections for codifying and organizing scientific principles. However, the output of this wonderful new knowledge would have been merely an intellectual exercise without the creativity and ingenuity of the engineering community, who created new practical products and processes from the ideas and visions emanating from this heady mix of science, technology, and business.

The social value of these activities is best examined through their contribution to the standard of living and the quality of life achieved in the 20<sup>th</sup> century. In addition to providing better health for the masses and remarkably increasing the length of our expected life span, these technologies have been at the center of our long-term economic success. In fact, if one evaluates the economies of the world today, the relationship between strong science and technology communities and economic prosperity is obvious. The major economies of North America, the Asiatic region (primarily Japan), and Western Europe account for over 85 percent of the world’s technical literature.

We are just beginning the 21<sup>st</sup> century, and the issues of science and technology and their relationship to social benefits, economic growth, and long-term national security should be a top priority for policymakers everywhere. The major discoveries and new products in the health sciences have been so dramatic in the last few decades that many feel

that the 21<sup>st</sup> century will be the “Century of Biology.” However, one must keep in mind that many of the discoveries and products based on DNA sequencing and other basic biology insights were possible because of new experimental techniques resulting from fundamental studies in the physical sciences. Areas like bioinformatics are based on mathematical principles. And many creative and innovative biological products and processes developed through engineering research and design. Therefore, it is more likely that the 21<sup>st</sup> century will be known as the era of integrated science, engineering, and innovative technology.

To protect U.S. leadership in this technology-based global environment and to continually replenish the science and technology pool that will define the economy and our way of life in the 21<sup>st</sup> century will require a national focus and priority on research in all of the sciences and engineering. This is clearly an area where the federal government must play a central role. The federal government must lead in the policy governing our investment in research; in funding research at our universities where our technical work force is created; in managing research necessary to carry out our national missions in defense, energy, the environment, health, and space; and in providing a climate for business investment.

In all of these areas the science and engineering communities must play a pivotal role, and the health, vigor, and relevance of their research agendas must be a national priority. In addition, since the bulk of our economy depends on an ever-expanding technically trained work force and the rapid translation of research into services and manufacturing processes and products, the replenishment and growth of that work force must be a major focus of any science and technology policy.

It is clear that during the 20<sup>th</sup> century, the United States progressed from a follower into a viable competitor and finally a leader in science and technology. Our leadership position has been aided by a continual stream of talented immigrants and by the fact that our country was essentially the only industrialized nation not severely damaged by the violence of World War II. Thus, the question for all of us today is, “Will we continue to be leaders in science and technology as we progress 10 or 20 years into the 21<sup>st</sup> century?”

Clearly there is no shortage of scientific and technological ideas. Very exciting things are happening in science, particularly in the programs that require teams of investigators from several disciplines. For example, the ultimate utility of quantum physics is now being exploited in

work focused on quantum computing. Several groups around the world are hard at work attempting to harness quantum particles to create a computer processor of unbelievable speed compared with today's fastest computer. This research is not just the purview of physicists and mathematicians. It requires chemists, materials scientists, and electrical engineers to invent and create a working model. Some of the most exciting work in the field is being done in government and industrial labs where such interdisciplinary teams can be assembled and focused on the overall goal. Some of the most successful academic labs have also managed to assemble teams of scientists and graduate students with varied backgrounds. Similar examples can be cited in nanotechnology, molecular biology, astronomy, and other areas of current intense interest. This limited list shows that there is no lack of useful, exciting, and relevant science and engineering challenges to occupy the minds and hands of our scientific community.

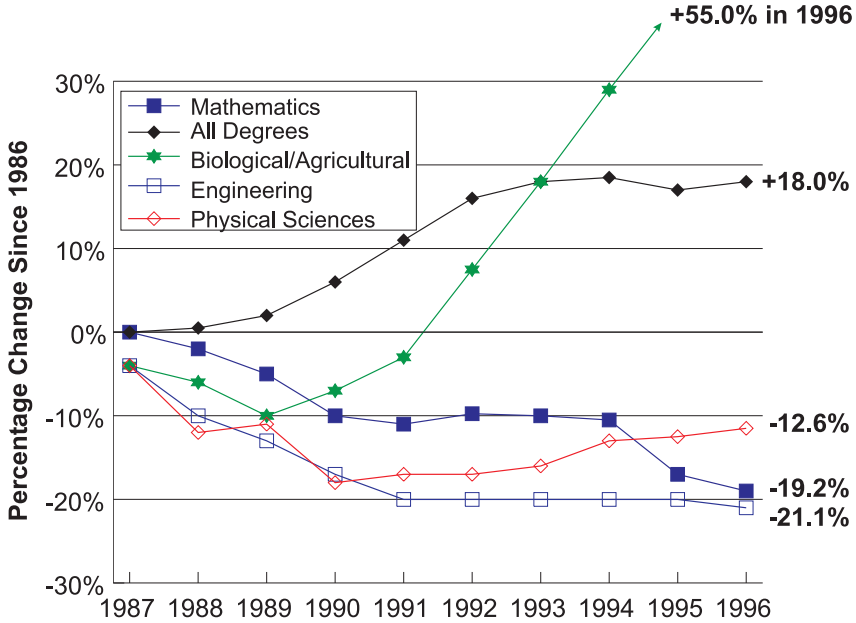
One attribute of the new century is the astonishing productivity of individual scientists and engineers using the research tools that have been developed over the last 50 years. My "educated guess" is that the content of one Ph.D. thesis today in any science or engineering discipline represents new knowledge that would have been the product of at least ten such theses 25 years ago. In fact, most of today's graduate students would find the theses of their mentors quite unchallenging.

In contrast to ideas, we have a decreasing cadre of professionals in the sciences and engineering, with the exception of the life sciences. Since 1986, B.S. degrees in engineering, mathematics, and the physical sciences have dropped by about 13 to 21 percent, while the number of all degrees has increased by 18 percent, and the number of degrees in the biological and agricultural sciences has increased by 55 percent (see Figure 1).

A recent report to NSF by the University of Chicago's National Opinion Research Center indicates that Ph.D. degrees in engineering peaked in 1996 at 6,305 and dropped 15 percent to 5,337 in 1999.<sup>5</sup> Physical sciences saw a similar pattern, peaking in 1994 at 3,977 and dropping to 3,582 in 1999. A large fraction of the decrease was in physics, although chemical Ph.D.s dropped as well. Mathematics and computer science also decreased, although by lesser percentages. Since the average time from B.S. to Ph.D. is about seven years, this would imply that the decrease started with the entering classes of 1992 and 1993.

The engineering class of 1999 contained 49 percent non-U.S. citizens, with 41 percent having only temporary visas. Of those with temporary visas, 22 percent planned postdoctoral study, 50 percent planned indus-

**Figure 1**  
**Change in Bachelor's Degrees Awarded Since 1986**



Source: Bureau of Labor Statistics

try employment, and 22 percent expected to go abroad. For those temporary visa holders in the sciences, 45 percent expected to do postdoctoral study, 15 percent planned to go into industry, and 27 percent planned to go home. Table 1 indicates the nonresident Ph.D. production in various disciplines.

The decreases in professional degrees in science and engineering are coming at the same time that U.S. industry is increasing its R&D expenditures (see Figure 2).

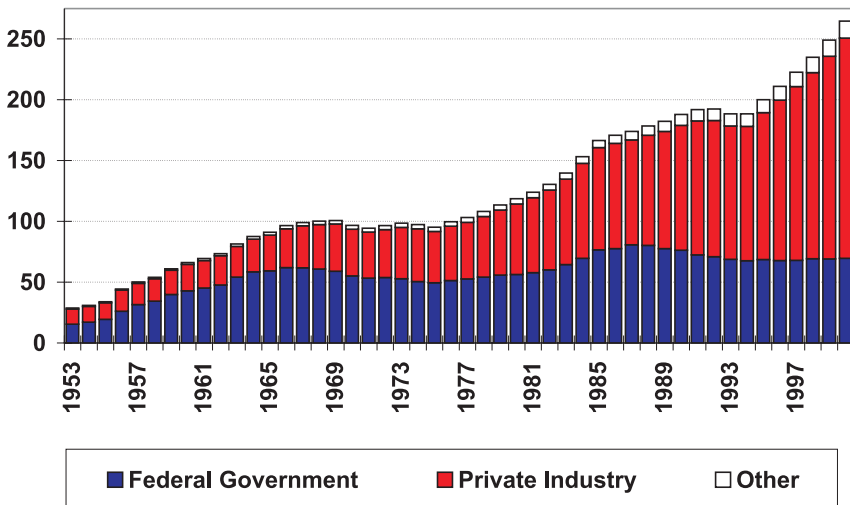
This year Congress has allowed the immigration of 200,000 H-1 visa holders to help fill job openings in the United States, especially in the information technology field. When one compares our work force with that of our global competitors, we find that we lag behind most of the industrialized world in the percentage of 24-year-olds with natural science and engineering degrees (see Figure 3).

**Table 1**  
**Demographics of the Ph.D.s: Percent of Degrees to Non-Residents**

• Engineering	48%
• Computer Science	43%
• Mathematics	47%
• Physical Sciences	35%

*Prepared by Duncan Moore, OSTP from data provided by the National Center for Education Statistics*

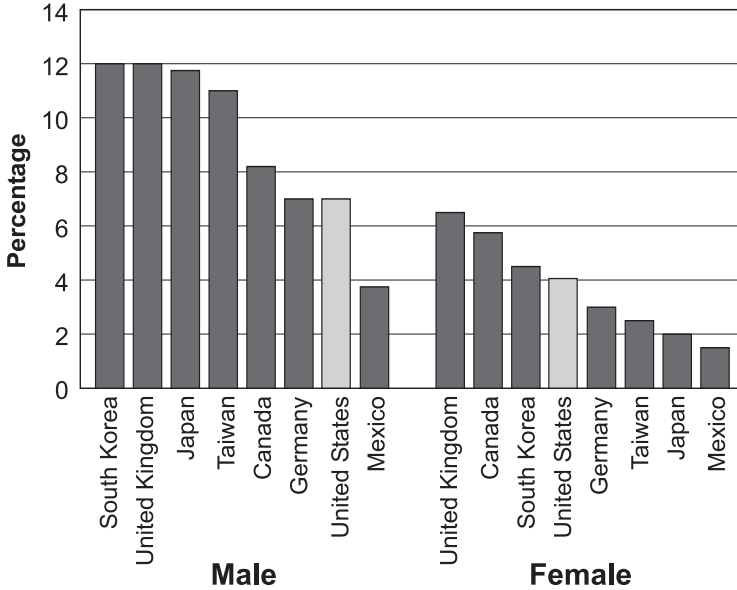
**Figure 2**  
**U.S. R&D Funding by Source, 1953–2002**  
**Expenditures in Billions of Constant 2000 Dollars**



Source: AAAS Report XXVI: Research and Development FY 2002

**Figure 3**  
**Global Competitiveness: Workforce**

**Percent of 24-Year-Olds with Natural Science and Engineering Degrees**



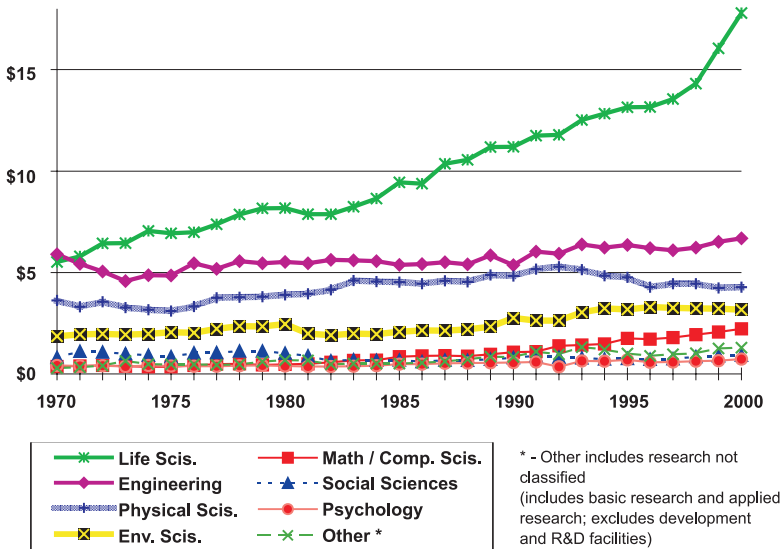
Source: *The Council on Competitiveness*

Another measure of our leadership position is given in a paper from the Centre for Technology Management at the Administrative Staff College of India.<sup>6</sup> The authors describe the R&D spending and patenting patterns of the top 500 global firms. The data show the dominance of U.S. firms, but not in all categories. In electronics, the United States has three of the top ten firms in R&D spending and patent production. In pharmaceuticals, the United States has six firms in the top ten. However, in chemicals, only three U.S. firms are in the top ten, and they have decreasing patent portfolios. In computer companies, six out of the top ten are based in the United States. In biotechnology, however, all top ten firms are headquartered in the United States. These statistics would indicate that the United States is clearly a leader in biotechnology and information technology. However, our nation is beginning to fall behind in areas where we were once the leader, such as chemicals and electronics (where we lost our lead two decades ago).

One measure of the country’s commitment to leadership in science and technology is its outlay for science and engineering research (see Figure 4). Here the picture is mixed. Health sciences continue to receive generous funding, but most other areas have seen decreases in their funding over the last ten years. Mathematics (including computer science), the physical sciences, and engineering have seen their support eroding.

The question is often asked, “What is enough funding?” One way to answer that question is to see if the funding has kept up with the gross national product (GNP) (see Figure 5). This can be argued as a good measure if you believe (and the economists have so calculated) that technological input is a major driver of the economy. Again, only the health sciences have kept up with the GNP. This would indicate that NIH is not over-funded, but that the science and technology base of the non-health industry is being challenged. Our leadership in these industries, including the knowledge-based industries, may be in jeopardy.

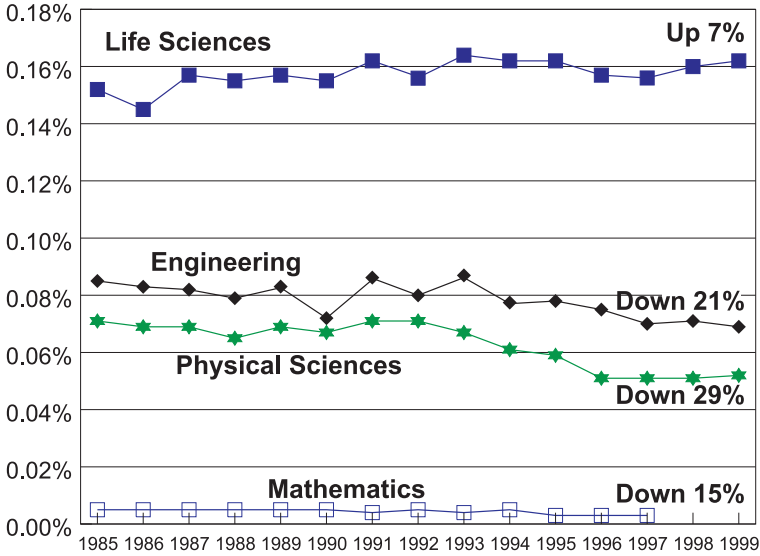
**Figure 4**  
**Trends in Federal Discipline, FY 1970–2000**  
**Obligations in Billions of Constant FY 2001 Dollars**



Source: AAAS Report XXVI: Research and Development FY 2002

**Figure 5**  
**Federal R&D as a Share of GDP**

**Life Sciences Up...Engineering, Physical Sciences and Math Down**



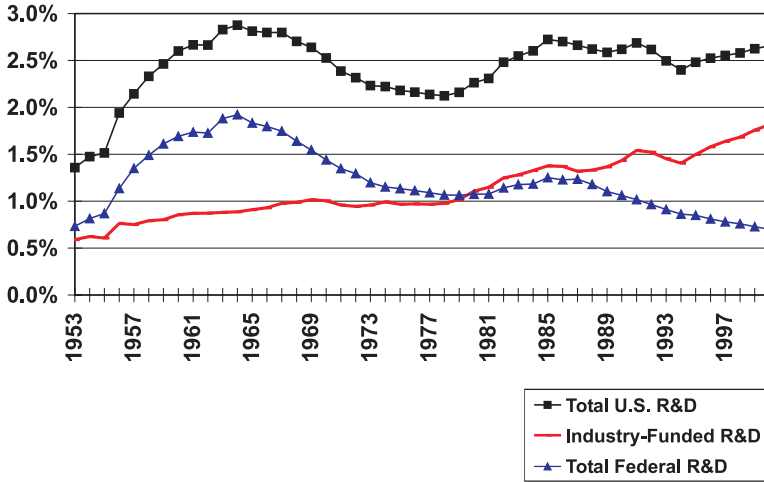
Source: NSF

At the same time, industrial R&D, with a heavy emphasis on development, is continuing to outpace the rise in GNP (see Figure 6). This would suggest that the underlying science and technology research pool will not be sufficient to sustain this growth over time.

To return to the question of science and technology policy: what needs to be done to provide the framework for our success in the 21<sup>st</sup> century? The history of the rapid rise of the United States as a science and technology leader in the later part of the 20<sup>th</sup> century illustrates how rapidly the world can change. Today, the United States does about one-third of the world's R&D, compared with our approximately 70 percent share in 1970. China produces over twice as many engineering graduates as we do, and Japan graduates 75 percent more (see Table 2).

**Figure 6**  
**U.S. R&D as Percent of GDP 1953–2000**

**Total, Industrial, and Federal R&D**



Source: AAAS Report XXVI: Research and Development FY 2002

**Table 2**  
**Undergraduate BS Engineering Degrees**

	<b>Total</b>	<b>% of BS/BA Degrees</b>
China	148,000	45.7%
Russia	131,000	32.4%
Japan	102,951	19.6%
France	20,600	18.9%
South Korea	41,300	18.7%
UK	23,300	9.3%
United States	63,400	5.4%

Source: National Center for Education Statistics

Our graduate programs in science and engineering are heavily dependent on non-U.S. citizens. This problem was analyzed very well in an April 2000 report from National Science and Technology Council.<sup>7</sup> It concluded, “If current trends persist, our nation may begin to fall far short of the talent needed to spur the innovation process that has given America such a strong economy and high quality of life.” If these trends in student output continue, and if the overall research budget does not keep up with the rise of our GNP and the rate of development of our industries, the United States in 25 years could be in a much less competitive position than it is today. This would affect our overall well-being and present a threat to our national security.

Potential threats to our long-term health and prosperity have been identified by a number of influential and thoughtful people. Paul Romer, the well-known economist from Stanford University, gained a front-page spot in *The Wall Street Journal*, for his discussion of the critical shortage of technically trained people and his ideas for turning the situation around.<sup>8</sup> John Cary reported in the March 1999 issue of *Business Week* that economists from Harvard University and the Massachusetts Institute of Technology found that the United States, versus other parts of the industrialized world, was falling behind in the “innovation index,” based on R&D funding and other factors.<sup>9</sup> David Gergen, in an editorial in *U.S. News and World Report* pointed out that “the U.S. economy leads the world, but its foundations are rusting.”<sup>10</sup> Debra van Opstal from the Council on Competitiveness wrote in the winter 1998 edition of *Issues in Science and Technology* that “Executives from every sector [of the industry] are concerned that the unique set of conditions that propelled the United States to a position of world leadership over the past 50 years may not be sufficient to keep us there over the next 50.”<sup>11</sup>

Perhaps the most recent comprehensive study of the state of American science and education is contained in chapter two of *Road Map for National Security: Imperative for Change* (the “Hart-Rudman Report”).<sup>12</sup> (See Chapter 34.) This chapter, “Recapitalizing America’s Strengths in Science and Education,” summarizes the nation’s needs in clear language: “The harsh fact is that the U.S. need for the highest quality human capital in science, mathematics, and engineering is not being met ... If the United States does not invest significantly more in public research and development, it will be eclipsed by others.” This Commission report, unlike many other studies and reviews, provides specific, time-based recommendations. The major ones are:

- The U.S. government's investments in science and technology research and development should double by 2010.
- The President's science advisor should be empowered to establish nonmilitary R&D objectives to meet changing needs and be responsible for coordinating budget development within the relevant agencies.
- The national laboratories should be reorganized to provide laboratory-specific missions with minimal overlap between laboratories.
- A National Security Science and Technology Education Act should be enacted and funded to provide: reduced-interest loans and scholarships for students in science, math, and engineering; loan forgiveness and scholarships for those entering government or military service; a teaching program to foster science and math teaching at the K-12 level; and increased funding for the professional development of science and math teachers.
- Targeted programs should be devised to provide incentives for minorities to pursue math, science, and engineering careers.

This report reflects an in-depth study of the problems and recommends some practical, specific things that can be done in a short time frame. It is worthwhile reading for anyone who has an interest in this area.

I want to make a few recommendations of my own. First, the scientific and engineering communities must come together and weigh in on both the work force issue and the research support issues. To be effective, they must rise above their own parochial interests and help develop specific proposals to address both issues in a global sense rather than from the narrow view of their own university, their own microcosm of science, or the competition to their own interests. Such an effort, if successful, will raise all boats, and personal interests can be realized in the details of the programs. Perhaps it is time for some organization like AAAS to play a convening role for such an effort and to provide an umbrella for working groups of scientists and engineers to put forward suggested solutions. Such suggested solutions could be vetted by industrial and government working groups to present consensus-backed proposals to Congress and the Administration.

Second, the government needs to recognize and showcase the vital role played by research, development, and technically trained people. I strongly agree with the Hart-Rudman report recommendation for a strengthened Office of Science and Technology Policy with more authority and responsibility for technical work force and civilian R&D issues. In fact, I think it is time for the federal government to establish a Cabinet position for science and technology. Such an office should be responsible for the coordination of federal R&D; for a complete review of government laboratories with the aim of significantly reducing bureaucratic overheads and returning responsibility for mission execution to local laboratory administrators; and for designing and executing programs that provide incentives for students to enter science, math, and engineering careers. This Cabinet officer should also establish an office to deal directly with university issues, with the goal of increased enrollment through expanded traineeships at the graduate level and targeted scholarships at the undergraduate level. The goal should be to increase the pool of students capable of science, math, and engineering careers, and to concentrate on the brightest and best-prepared students.

Finally, the problem is beginning to be so great that the usual “fixes” and “tinkering around the edges” will not be enough. Enough motivated people both in and out of government must see the need and begin to work together for the common good.

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