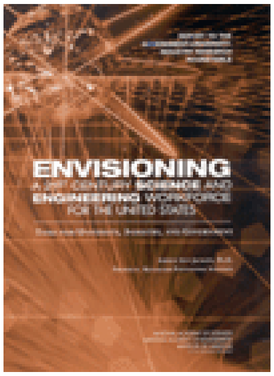

Envisioning A 21st Century Science and Engineering Workforce for the United States: Tasks for University, Industry, and Government

Shirley Ann Jackson, PH.D., President, Rensselaer Polytechnic Institute, National Academy of Sciences, National Academy of Engineering, Institute of Medicine

ISBN: 0-309-50649-2, 32 pages, 7 x 10, (2003)

REPORT TO THE GOVERNMENT-UNIVERSITY-INDUSTRY RESEARCH ROUNDTABLE

ENVISIONING A 21ST CENTURY SCIENCE AND ENGINEERING WORKFORCE FOR THE UNITED STATES

TASKS FOR UNIVERSITY, INDUSTRY, AND GOVERNMENT

SHIRLEY ANN JACKSON, PH.D.
PRESIDENT, RENSSELAER POLYTECHNIC INSTITUTE

The views expressed are those of the author and do not represent an official policy statement of the Government-University-Industry Research Roundtable nor of its sponsoring organizations or the National Academies.

THE NATIONAL ACADEMIES PRESS
Washington, D.C.
www.nap.edu

THE NATIONAL ACADEMIES PRESS • 500 Fifth Street, N.W. • Washington, DC 20001

This paper was supported by Contract/Grant No. NASW-99037 between the National Academy of Sciences and NASA, and Contract/Grant No. 50SBNB0C2025 between the National Academy of Sciences and NIST. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author and do not necessarily reflect the views of the organizations or agencies that provided support for the project.

International Standard Book Number 0-309-08856-9

Additional copies of this report are available from the National Academies Press, 500 Fifth Street, N.W., Lockbox 285, Washington, DC 20055; (800) 624-6242 or (202) 334-3313 (in the Washington metropolitan area); Internet, http://www.nap.edu

Printed in the United States of America

THE NATIONAL ACADEMIES

Advisers to the Nation on Science, Engineering, and Medicine

The **National Academy of Sciences** is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. Upon the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Bruce M. Alberts is president of the National Academy of Sciences.

The **National Academy of Engineering** was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. Wm. A. Wulf is president of the National Academy of Engineering.

The **Institute of Medicine** was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, upon its own initiative, to identify issues of medical care, research, and education. Dr. Harvey V. Fineberg is president of the Institute of Medicine.

The **National Research Council** was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Dr. Bruce M. Alberts and Dr. Wm. A. Wulf are chairman and vice chairman, respectively, of the National Research Council.

www.national-academies.org

". . . If the S&E workforce is inadequate to need, the nation's innovation engine will slow, curtailing U.S. competitiveness in a global economy . . ."

THE ROUNDTABLE COUNCIL

". . . The United States achieved pre-eminence in science and technology partly because it was able to recruit and educate the best talent from around the world."

PREFACE

The Government-University-Industry Research Roundtable (GUIRR) of the National Academies has a continuing interest in science and engineering (S&E) workforce issues. The Roundtable convened a workshop on this subject in October 2001 and held a pan-organizational summit meeting in November 2002. Specific concerns were the S&E workforce needs of the federal government and the additional challenges that scientific and technical agencies face. To further inform its discussions, GUIRR asked Dr. Shirley Ann Jackson, President, Rensselaer Polytechnic Institute, to present her position on these issues in a report to the Roundtable. The statements made in this paper are those of the author and do not necessarily represent positions of the Roundtable or the National Academies.

This paper has been reviewed in draft form by individuals chosen for their expertise, in accordance with procedures approved by the National Academies Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will ensure that the report meets institutional standards for quality. The review comments and draft manuscript remain confidential to protect the integrity of the process.

We wish to thank the following individuals for their review of this paper:

Willie Pearson, Georgia Institute of Technology
Helga Rippen, RAND Science and Technology Policy Institute
Jonathan Yochelson, BEST Initiative (Building Engineering and Science Talent)

Although the reviewers listed above have provided constructive comments and suggestions, they were not asked to endorse the content of the paper. Responsibility for the final content of the paper rests with the author.

Marye Anne Fox
Co-Chair, GUIRR

William H. Joyce
Co-Chair, GUIRR

CONTENTS

". . . African-Americans and ethnic minorities constitute 24 percent of the total population but only 7 percent of the S&E labor force."

INTRODUCTION

For decades, the United States has operated as a nation with few peers. As a result, Americans implicitly assume that the United States will prevail in any contest. But both national security and economic status in a global economy has relied primarily on technological superiority. The world is driven by processes and goods with a high technical content; and superiority, competitiveness, and progress rely upon a nation's ability to muster a technically trained workforce. Based on data obtained from sources such as the World Bank, the National Science Foundation, the National Center for Education Statistics, the Council on Competitiveness, and others, there is growing evidence that U.S. dominance in this regard is eroding:

- Centers of technological excellence,[1] advanced training,[2] and entrepreneurial activity[3] are rapidly spreading throughout the globe.
- Thus, even the status quo for the United States represents a declining share of the global marketplace for people and ideas.[4]
- Not enough U.S. students are choosing majors in science, mathematics, engineering, and technology to maintain this status quo, much less sustain global leadership.[5,6]
- International testing shows that the United States ranks well behind other nations in the science, mathematics, engineering, and technology achievement of our citizens,[7] and our production of science and engineering Ph.D.s.[8,9]
- Technologies for counter-terrorism and homeland security are outcomes of earlier U.S. investments in science, technology, and education. Many of these technologies have been built upon the work of international scientists who immigrated to this country.[10]

- The United States has relied on importing talent on H1B visas when it has been unable to find the science and technological professionals at home.[11] This practice has shielded the United States from experiencing a growing domestic shortage.

Because the federal government relies heavily, though not exclusively, on the private sector for much of its research and development, federal and private sector science and engineering (S&E) workforce needs are necessarily intertwined. The question of responsibility for workforce planning therefore arises. Is it the federal government's responsibility to step in and take action? If so, what action?

This paper reviews options to manage and to mitigate the risks to U.S. technological advantage.

---

[1] Michael E. Porter and Debra van Opstal. *U.S. Competitiveness 2001: Strengths, Vulnerabilities and Long-Term Priorities* [p. 35]. Washington, DC: Council on Competitiveness, 2001. Original Source: Michael E. Porter and Scott Stern. *The New Challenge to America's Prosperity: Findings from the Innovation Index.* Washington, DC: Council on Competitiveness, 1999.

[2] "The scale of doctoral programs has increased in several world regions, particularly Europe, Asia, and the Americas. This capacity building in doctoral S&E education is linked to national policies to develop an S&E infrastructure that more explicitly links universities to innovation and economic development." (National Science Foundation. *Science and Engineering Indicators 2002* [p. 2-41 & 2-43]. Arlington, VA: NSF, 2002. Available online: http://www.nsf.gov/sbe/srs/seind02/start.htm).

[3] "Foreign R&D expenditures for U.S. companies makes up 10.5 percent of all company-financed expenditures in 1997, and has grown in absolute dollars from 8 billion in 1989 to 14 billion in 1997." U.S. Department of Commerce. Office of Technology Policy. *Globalizing Industrial Research and Development* [p. 35]. Washington, DC: Government Printing Office, 1999. Original source: U.S. Department of Commerce. Bureau of Economic Analysis. *U.S. Direct Investment Abroad: Operations of U.S. Parent Companies and Their Foreign Affiliates.* Washington, DC: U.S. Government Printing Office, annual b.

[4] Declining indicators include: **U.S. fraction of global R&D investment** (Michael E. Porter and Debra van Opstal. *U.S. Competitiveness 2001: Strengths, Vulnerabilities and Long-Term Priorities* [p. 32]. Washington, DC: Council on Competitiveness, 2001. Original source: National Science Foundation. Science and Engineering Indicators 2000 [Figure 2-27]. Arlington, VA: NSF, 2001. Available online: http://www.nsf.gov/sbe/srs/seind00/frames.htm); **Fraction of worldwide peer-reviewed scientific papers authored by U.S. scientists** (Michael E. Porter and Debra van Opstal. *U.S. Competitiveness 2001: Strengths, Vulnerabilities and Long-Term Priorities* [p. 33]. Washington, DC: Council on Competitiveness, 2001. Original Source: World Bank, *World Development Indicators 2002* CD-ROM.); **Proportion of domestic population earning science and engineering degrees** (Michael E. Porter and Debra van Opstal. *U.S. Competitiveness 2001: Strengths, Vulnerabilities and Long-Term Priorities* [p. 21]. Washington, DC: Council on Competitiveness, 2001. Original Source: NCES. *International Education Indicators: A Time Series Perspective, 1985-95* [Tables 15-1 and 15-4]. Washington, DC: Government Printing Office, 1999.); **Number of practicing scientists and engineers in the U.S.** (National Science Foundation. *Science and*

Engineering Indicators 2002 [Appendix Table 2-34]. Arlington, VA: NSF, 2002. Available online: http://www.nsf.gov/sbe/srs/seind02/start.htm).

[5] National Science Foundation. *Science and Engineering Indicators 2002* [Appendix Table 2-18], Arlington, VA: NSF, 2002. Available online: http://www.nsf.gov/sbe/srs/seind02/start.htm).

[6] Michael E. Porter and Debra van Opstal. *U.S. Competitiveness 2001: Strengths, Vulnerabilities and Long-Term Priorities* [p. 21]. Washington, DC: Council on Competitiveness, 2001.

[7] Ina V. S. Mullis, Michael O. Martin, Albert E. Beaton, Eugenio J. Gonzalez, Dana L. Kelly, and Teresa A. Smith. *Mathematics and Science Achievement in the Final Year of Secondary School: IEA's Third International Mathematics and Science Study* [pp. 1-10]. Boston, MA: Center for the Study of Testing, Evaluation, and Educational Policy, 1998

[8] "The combined doctoral S&E degrees of the three largest European countries (Germany, France, and the United Kingdom) recently surpassed the number of U.S. earned degrees." (National Science Foundation. *Science and Engineering Indicators 2002* [p. 2-42 & Appendix Table 2-40], Arlington, VA: NSF, 2002. Available online: http://www.nsf.gov/sbe/srs/seind02/start.htm).

[9] "Universities within five Asian countries are now producing more engineering doctorates than universities within the United States. The gap is even larger, since half of the U.S. degrees are earned by foreign students, the majority of whom are Asian." (National Science Foundation. *Science and Engineering Indicators 2002* [p. 2-41 & Appendix Table 2-33 and 2-39]. Arlington, VA: NSF, 2002. Available online: http://www.nsf.gov/sbe/srs/seind02/start.htm).

[10] The National Academies. *Science, Technology and the Federal Government: National Goals for a New Era* [Chapter 1]. Washington, DC: National Academy Press, 1993.

[11] Growth in H1B visas is documented in the following: National Science Foundation. *Science and Engineering Indicators 2002* [Appendix Table 2-26]. Arlington, VA: NSF, 2001. Available online: http://www.nsf.gov/sbe/srs/seind02/start.htm).

THE PROBLEM

The United States is facing a crisis in science and engineering talent and expertise. For decades, U.S. scientific and technological production and innovation flourished, largely because of the nation's ability to recruit talented American students into the science and engineering disciplines, and when domestic talent was unavailable, to import the best scientists and engineers from around the world.

The shifting of traditional forces and balances contributes to this crisis. Americans live longer and spend less of their lives working. Only now—for the first time in 30 years—is the birthrate exceeding replacement.[12] The result is a shrinking workforce, and despite an economic downturn, there is an unprecedented labor shortage, with thousands of jobs going unfilled.[13]

The demographics of the United States are changing. Women and minorities together make up 60 percent of the total workforce,[14] but they are dramatically underrepresented in S&E. Women comprise 46 percent of the total labor force, but only 23 percent of the S&E labor force.[15] African Americans and ethnic minorities constitute 24 percent of the total population but only 7 percent of the S&E labor force.[16] This means the majority of Americans is underrepresented in S&E.

Furthermore, a large cohort of S&E professionals educated in the 1950s and 1960s is soon to retire and fewer U.S. students are choosing careers in S&E.[17]

The result is that the domestic S&E workforce is dwindling, and future projections are not encouraging. The United States achieved pre-eminence in science and technology partly because it was able to recruit and educate the best talent from around the world. However, a number of factors are beginning to make it more difficult for the nation to continue to rely on foreign talent, and it now is unclear whether the nation can expect to have an adequate supply of scientists and engineering professionals needed to maintain its long-established global leadership.

Many interested parties have issued reports on their findings and are conducting studies on this important planning issue. Key among them was the February 2001 report issued by the U.S. Commission on National Security/21st Century, commonly referred to as the "Hart-Rudman Report".[18] It states unequivocally:

> *"Second only to a weapon of mass destruction detonating in an American city, we can think of nothing more dangerous than a failure to manage properly science, technology, and education for the common good over the next quarter-century."*

Another report, "The Commission to Assess United States National Security Space Management and Organization,"[19] similarly warned:

> *"Government needs to play an active and deliberate part in expanding and deepening the pool of military, civilian, and commercial talent in science, engineering, and systems operations the nation will need to maintain its position as the number one space-faring country in the 21st century."*

In January 2001, the U.S. General Accounting Office (GAO) placed development of federal human capital on its list of high-risk issues. Fewer than eight months later, the *President's Management Agenda*[20] cited workforce planning and restructuring as one of five critically needed government-wide management reforms.

The concern over the adequacy of the nation's S&E workforce is an issue rising to the top of many federal and corporate agendas.

---

[12] U.S. Department of Health and Human Services. National Center for Health Statistics. *National Vital Statistics Report,* Vol. 5, No. 5. Washington, DC: DHHS, Feb 12, 2002.

[13] Dr. Shelly Hymes, Executive Director, U.S. Dept. of Labor. Office of the 21st Century Workforce. Oct 24, 2001. Personal Communication.

[14] U.S. Department of Labor. Bureau of Labor Statistics. *Report on American Workforce* [Table 5, p. 126]. Washington, DC: Government Printing Office, 2001

[15] National Science Foundation. *Science and Engineering Indicators 2002* [p. 3-12]. Arlington, VA: NSF, 2002. Available online: http://www.nsf.gov/sbe/srs/seind02/start.htm).

[16] National Science Foundation. *Science and Engineering Indicators 2002* [p. 3-13]. Arlington, VA: NSF, 2002. Available online: http://www.nsf.gov/sbe/srs/seind02/start.htm).

[17] National Science Foundation. *Science and Engineering Indicators 2002* [Figure 2-11]. Arlington, VA: NSF, 2002. Available online: http://www.nsf.gov/sbe/srs/seind02/start.htm).

[18] U.S. Commission on National Security/21st Century. *Road Map for National Security: Imperative for Change* [p.30]. Washington, DC: Government Printing Office, 2001.

[19] Commission to Assess United States National Security Space Management and Organization. *Report to Congress* [p. 10]. Washington, DC: Government Printing Office, 2001.

[20] Office of Management and Budget, *The President's Management Agenda, FY 2002*. Washington, DC: Government Printing Office, 2001.

UNDERSTANDING THE RISKS TO THE S&E WORKFORCE

In recent times, efforts have been made not only in the private and non-profit sectors but also in a variety of federal departments and agencies to determine the nature of the risks and the consequences to the United States of undervaluing and relying on market forces to engender an adequate S&E workforce. Taken singly, no one risk is debilitating. Taken together, there is substantial cause for concern.

- **The federal S&E workforce is shrinking:** The Department of Defense S&E workforce declined from 45,000 to 28,000 in the decade between 1990 and 2000.[21] Many more will soon retire. Other agencies reflect the same pattern. Approximately 45 percent of all scientists and engineers employed in the federal government are 45 years of age or older.[22] Federal agencies have not hired scientists and engineers in significant numbers in recent years.

- **The ability to recruit talent from abroad may be limited in the future.** Historically, the United States recruited globally and had access to the best minds worldwide. Several factors may reduce this source. Legislative pressure to restrict immigration increased in the wake of September 11, 2001. Several bills have been passed into law since September 11 to prevent suspected terrorists from entering the United States through loopholes in immigration laws and the nation's visa system.[23, 24]

- **Comparable opportunities are luring foreign students home.** Nations that once supplied much of the U.S. foreign S&E workforce, such as South Korea, now have the ability to provide their own students and graduates with first-world opportunities. Other countries, such as China, are moving swiftly in the same direction.

- **"Stay rates" of foreign scientists and engineers cannot rise much farther:** "Stay rates" of foreign students have been both stable and relatively high. Between 1994 and 1999, the overall rate was 63 percent, with 73 percent in the physical sciences, 66 percent in mathematics, and 81 percent in computers and electrical engineering.[25] There appears to be little room for "stay rate" increases in some disciplines, eliminating this as a solution to looming shortages.[26]

- **Underutilization of talent in the United States.** Unless the nation makes a more serious effort to inspire, educate, and recruit minority students to S&E, it will neglect huge potential contributions by its own population that would be significant to replenish the talent lost to retirement.

- **The education gap is growing.** There is a big difference between providing new jobs and the training of the workforce. Skill sets required for jobs do not necessarily match the skill sets or disciplinary boundaries of degree programs. The declining percentage of doctorates compared to the total S&E workforce, in itself, indicates workers with less expertise in the most needed skill sets.

- **The lack of adequate data hampers policy making.** There is a lack of reliable data to serve as a platform for public policy. For instance, there are no reliable data on what happens to individuals with H1B visas, or what happens to the graduates from community colleges, which also contribute to the S&E workforce. Nor is there reliable workforce data at the sub-field level, where much of the "biocentric" activity in the physical sciences (e.g., biophysics, growth in bioelectronics, and biomechanics) is taking place.[27]

Changing circumstances can create temporary or specific exceptions to any one risk mentioned above. Yet, as a whole, the risks combine to paint a very sobering picture of future U.S. competitiveness in science and engineering talent.

---

21 U.S. House. Armed Services Committee. *Testimony of Undersecretary of Defense for Acquisition, Technology and Logistics Pete Aldridge*. 12 July 2001.

22 National Science Foundation. *Women, Minorities and Persons with Disabilities in S&E* [Appendix Table 5-22 (1997)]. Arlington, VA: NSF, 2000.

23 U.S. House. 107th Congress, 2nd Session. H.R. 3525, *Enhanced Border Security and Visa Entry Reform Act of 2002*. Available online: http://www.access.gpo.gov/congress/cong009.html [December 6, 2002].

24 U.S. Senate. 107th Congress, 2nd Session. *A bill to amend the Immigration and Nationality Act to provide permanent authority for the admission of "S" visa non-immigrants.* Available online: http://www.access.gpo.gov/congress/cong009.html [December 6, 2002].

25 Michael G. Finn. *Stay Rates of Foreign Doctorate Recipients from U.S. Universities* [Table 1]. Oak Ridge, TN: Oak Ridge Associated Universities, 2001.

26 Ibid, p. 3.

27 Committee to Assess the Portfolio of the Division of Science Resources Studies of NSF. *Measuring the Science and Engineering Enterprise* [pp. 66, 72, 76]. Washington, DC: National Academy Press, 2000.

THE **RISKS** OF A **DECLINING S&E** WORKFORCE

What are the consequences of these demographic shifts that threaten the adequacy of the national S&E workforce? The risks are real. The nation risks losing a favorable trade balance, and becoming vulnerable to the unexpected, such as a major energy crisis, a national health emergency, a military threat, or terrorist attack. A decline in the availability of foreign workers would compound these risks.

- **The nation risks losing international, business, and economic leadership.** If the S&E workforce is inadequate to need, the nation's innovation engine will slow, curtailing U.S. competitiveness in a global economy that is revving up with unprecedented vigor. Bill Joyce, CEO of Hercules Incorporated, has summarized the situation:

> *"If there are not enough trained people in the U.S., corporations will have to move R&D operations to countries where the trained people are. The pilot plant follows, because you need the R&D people nearby to help make it work. The manufacturing plant follows the pilot plant. Distribution, sales, and management follow the manufacturing. Once this process is started, it is not reversible. Corporations may not like it, but they will survive if there is no R&D in the U.S. The U.S. economy, however, will not recover from the loss of this business.*[28]

- **Advances in the physical sciences will decline.** Capability in basic science is essential to the three major emergent areas of research and innovation: biotechnology, nanotechnology, and information technology. Because of substantial budgetary shifts favoring the life sciences, losses in the physical sciences are magnified. The share of federal funding devoted to the physical sciences experienced a 17.7 percent decline from 1993 to 1999.[29] Ironically, the overwhelming majority—74.2 percent—of industrial R&D performed in the United States is based in the physical sciences, math, and engineering fields and requires workers with training in those backgrounds.[30]

The Director of the National Science Foundation, Rita Colwell, has said,

> *"This message has to be shouted. It can't continue. We're down 23-25 percent in math and physics, which is clearly a serious situation."*

- **The nation risks losing essential technological expertise.** With the pending retirements of older S&E professionals, the nation will lose experts in key disciplines, for example high-energy physics and nuclear engineering.

- **The nation's security-sensitive systems are at risk.** A dearth of educated U.S. citizens in sensitive technical areas (e.g., nuclear engineering, hypersonics) carries clear and specific national security risks. National technological superiority is part of the foundation of our present military strategy. John Marburger, Director of the White House Office of Science and Technology Policy, has cited the "Hart-Rudman Report" in support of this thesis. The Commission's work has focused on how American science and technology, as well as education in science and technology, can and should be revitalized to better support the nation's security needs and interests.[31]

In many western nations, government adopts a laissez-faire posture toward science and engineering talent development, relying on a market-based approach to foster the next generation of scientists and engineers. The United States can no longer afford to be so complacent.

[28] William Joyce. Government University Industry Research Roundtable. March 12-13, 2002. Washington, DC: National Academy of Sciences.

[29] Stephen A. Merrill. *Trends in Federal Support of Research and Graduate Education,* [p. 27]. Washington, DC: National Academy Press, 2001.

[30] Tim Studt and Dr. Jules J. Duga. "Smaller Increase Forecast for US Research Spending" [Table 3—International R&D]. Morris Plains, NJ: R&D Magazine. January 2002.

[31] U.S. Commission on National Security/21st Century. *Road Map for National Security: Imperative for Change*. Washington, DC: Government Printing Office, 2001.

STRENGTHENING THE S&E WORKFORCE

Government, industry, non-profits, and academia must engage the national will, if we are to be successful in rebuilding the science and engineering workforce. In the author's opinion, a list of priorities should include the following:

- **Recognize the key role of science and technology with respect to national security, in the wake of September 11, 2001.** The launch of Sputnik in October 1957 stunned Americans, who had thought the Soviets would never best them, and created fear that their Cold War enemy might catch up militarily. As a result, the United States passed the National Defense Education Act, quickly producing government and private aid programs that recruited young people to S&E, and tripled the National Science Foundation (NSF) budget. Similarly, September 11 triggered a patriotic response and a new awareness of the power of technology to protect the homeland, to strengthen the nation militarily, and to mitigate conditions that may foster terrorism. This realization could be used to kindle another national effort to encourage production of scientists and engineers.

- **Tap into the talent inherent in groups that are underrepresented in S&E.** The nation has the opportunity to develop the talents of all young people, including those who traditionally have not chosen to study S&E and have not been represented in the S&E workforce. At the Massachusetts Institute of Technology (MIT), for example, the hiring process has been deliberately changed to bring more underrepresented minorities to the faculty.[32] Summer undergraduate research fellowships provide one avenue of approach to attract students.

- **Emulate successful models.** In federal agencies and private industry alike, there are examples of programs that successfully stimulate interest in the study of S&E, engage youth in summer internship programs, fund graduate study and research, and increase the number of students that complete studies in S&E. One example is a U.S. Department of Transportation (DOT) program that supports transportation centers at universities. Their funds require a 100 percent match from a non-federal source.[33] These centers reach back into the K-12 school pipeline, building interest and offering incentives, such as the Eisenhower Fellows program, which provides grants for master's degree candidates and for some undergraduates. While only a few go on to work directly for DOT, 92 percent stay in transportation, which is the program's broader goal.[34] Other federal agencies sponsor similar programs.

  Examples of successful privately run programs include the U.S. First Robotic Competition, which engages more than 10,000 high school students across the country in design competitions in collaboration with industrial sponsors.[35]

- **Establish more graduate fellowship programs for women and minority groups that are underrepresented in S&E.** More could be accomplished by linking policy to need. For instance, although the U.S. Department of Education offers almost $20 billion in student aid, virtually none of it is tied to the need to enhance the workforce in a particular discipline. There are national needs not only in S&E, but also in teaching, nursing, and other disciplines that could be addressed by a more targeted student aid program. Loan forgiveness is another option, with students receiving an educational loan in return for working a specified number of years in the targeted discipline after completion of their terminal degree. Finally, programs modeled after the Pell grants could be established specifically for S&E majors, as well as portable fellowships.

- **Make better use of education research and modern teaching techniques.** Make use of cognition research to better inform pedagogy at all educational levels. Today's classrooms look much as they did in 1900. Knowledge of how students learn and use information has largely been ignored. The federal government has never invested a large amount of money in education research or in connecting that research to education practice. However, efforts to link technology and industry, as those at the NSF's Engineering Research Centers, have proven successful;[36] these may provide templates for other cross-sector/cross-discipline collaborations.

- **Establish discipline-based teacher models.** Teacher compensation must equal that of industry. Under this program, schools recruit from industry scientists and mathematicians who want to teach. The program expedites certification and offers a contract (of perhaps five years), especially in minority population school districts. These contracts would guarantee both teaching and summer employment in a local corporation and possibly corporate consulting during the teaching year. Being taught by these working scientists exposes students early to what science and technology is all about and to its career opportunities. The teachers, in turn, work on the leading edge of new technologies that inform their teaching. The program would also enhance the teacher/scientists' professional status and compensation, attracting more such teachers to the pre-college classroom.

- **Improve management practices, especially in government laboratories, to attract and retain S&E workers.** Design and implement alternative management systems that include such practices as pay for performance, competitive incentives, peer evaluation, and pay and promotions based on agency performance, rather than on years in service.

  - ❖ Establish dual, equal-status tracks for advancement in both technical and management positions. Consider more flexibility in hiring, allowing directors autonomously to hire personnel, approve flexibility in work schedules, and compensate workers.

  - ❖ Realize that successful managers must understand S&E sufficiently to manage well, but that successful scientists do not necessarily need to be good managers. Cross training of managers and scientists in the management of science, engineering, and technology would correct the disparity.

  - ❖ For government scientists and engineers, design work to be interesting and challenging to compete with the lure of higher earnings found in industry.

- **Promote grants that emphasize education and outreach.** Using the NSF peer-review grant model, focus on programs of strategic importance. One is the new federal Cyber Service program, which strengthens essential new fields, such as information assurance, through scholarships, stipends, and internships. This requires pinpointing disciplines or sub-disciplines with potential workforce shortfalls, such as aerospace and nuclear engineering. Finally, encourage the coordination of outreach and education programs among federal agencies.

- **Establish teaching fellowships.** These fellowships would reward tenured faculty for teaching S&E classes or innovations in S&E education.

- **Create a variety of programs to attract and encourage young women and minority groups into the S&E workforce.**

  - Private corporations and some federal science agencies have succeeded in attracting young people to their industries and to science disciplines through presentations in elementary schools, hosting middle and secondary school students in summer programs and providing internships for undergraduate and graduate students.

  - The National Action Council for Minorities in Engineering (NACME) and the Girl Scouts also have successful programs aimed at underrepresented demographic groups.

  - More than 234 students have graduated with degrees in science, engineering, and mathematics from the Meyerhoff Scholars program at the University of Maryland-Baltimore County (UMBC) since 1993. The program is the largest producer of African Americans who go on to science Ph.D.s.[37] The program combines top-quality research faculty and opportunities for S&E undergraduates to participate in research.

  - For such programs to succeed, at-risk eighth graders must be identified. Summers and weekends on campus allow these students to learn what real science is about.

- **Target graduate students through incentives.** For example, provide extra funding, which will allow them to achieve economic stability closer to that of their employed peers.

- **Gather better data.** Better data would inform policy-making and provide information for more effective funding investment. For instance, it would be useful to follow various cohorts—postdoctoral graduates, community college students, and middle school pupils—to uncover the points at which students in the S&E pipeline leave, and why.

- **Induce talented scientists to enter and remain in research by a campaign to renew interest in public service careers.**

- **Keep funding at appropriate levels.** During the 1990s, federal agencies' share of total R&D funds declined significantly, from approximately 40 percent of total to below 30 percent.[38] Federal agencies are now trying to increase funding. The lesson to learn is that consistent federal R&D funding is more important than the micromanagement of research.

---

32 Massachusetts Institute of Technology. *A Study on the Status of Women Faculty in Science at MIT.* Cambridge, MA: MIT Faculty Newsletter Vol. 11(4), 1999.

33 Legal Citation: 49 *USC* Sec. 5505 (2000).

34 Joseph Toole. Federal Highway Administration, October 23, 2001. Personal Communication.

35 For Inspiration and Recognition of Science and Technology (FIRST) 2002. Available online: http://www.usfirst.org.

36 Linda Parker. *The Engineering Research Centers Program: An Assessment of Benefits and Outcomes.* Arlington, VA: NSF, 1997. Available online: http://www.nsf.gov/pubsys/ods/getpub.cfm?nsf9840.

37 Freeman Hrabowski III. *The Meyerhoff Scholars Program: Producing High-Achieving Minority Students in Mathematics and Science.* Notices of American Mathematical Society [Vol. 48(1) p. 36]. Available online: http://www.ams.org/notices/200101/comm-hrabowski.pdf [17 Oct 2002].

38 National Science Foundation. *Science and Engineering Indicators 2002* [Figure 4-3]. Arlington, VA: NSF, 2002. Also available: http://www.nsf.gov/sbe/srs/seind02/start.htm).

CONCLUSION

For the United States to remain competitive in a vibrant global innovative and research environment, it must have access to the best minds. Congress and the public need to understand that the nation's pre-eminence rests on its technological strength which in turn depends entirely on its ability to attract, educate, recruit, and retain the best S&E workers. Assuring that the nation has the number and quality of scientists and engineers is a national imperative upon which the nation's security and prosperity rests entirely.

In many nations, the central government takes an active part in developing the science and engineering workforce. In the past, the United States has done the same—to secure victory over the Axis powers of World War II, to assure dominance in the arms race of the Cold War, and after Sputnik to win the space race. However, for the last 25 years, the U.S. federal government has left S&E workforce issues entirely to the marketplace.

The time has come again for action. Because building a science and engineering workforce has a long lead time, it requires immediate attention and swift, coordinated action by government, university, and industry.

Any opinions, findings, conclusions, or recommendations expressed within this document are those of the author and do not necessarily reflect the views of the National Academies.