ARISE

Advancing Research In Science and Engineering

Investing in Early-Career Scientists and High-Risk, High-Reward Research

AMERICAN ACADEMY OF ARTS AND SCIENCES

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AMERICAN ACADEMY OF ARTS AND SCIENCES
Cambridge, Massachusetts

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Please direct inquiries to:
American Academy of Arts and Sciences
136 Irving Street
Cambridge, Massachusetts 02138-1996
Telephone: (617) 576-5000
Fax: (617) 576-5050
Email: aaas@amacad.org
Visit our website at www.amacad.org

American Academy of Arts and Sciences

Committee on Alternative Models for the Federal Funding of Science

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Leslie C. Berlowitz (American Academy of Arts and Sciences), *ex officio*

Project Staff

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Katie Donnelly (American Academy of Arts and Sciences)

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- Mentoring a new generation of scholars and thinkers through the Visiting Scholars Program and the Hellman Fellowship in Science and Technology Policy;
- Honoring excellence by electing to membership men and women in a broad range of disciplines and professions.

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Executive Summary

Leadership in science and technology is necessary to compete effectively in the global economy. Today the dominant position of the United States in the international research and education community is being challenged as never before. Many concerned parties have focused on overall levels of federal funding as the means of sustaining America's competitive advantage. While funding levels are important, money alone cannot guarantee preeminence; a focus on modes and mechanisms of funding is critical.

The American Academy of Arts and Sciences assembled a committee of academic and business leaders to stimulate discussion of, and action on, two issues central to the nation's research efforts that have not received sufficient attention:

- Support for early-career faculty.
- Encouragement of high-risk, high-reward, potentially transformative research.

We strongly believe that, regardless of overall federal research funding levels, America must invest in young scientists and transformative research in order to sustain its ability to compete in the new global environment. In this report, we outline a series of recommendations for all key stakeholders, including government, universities, and foundations.

EARLY-CAREER FACULTY

Today's early-career faculty will be responsible for our country's future science and technology discoveries and for the education of our future Ph.D.-level scientists and engineers. Yet they face greater obstacles than their more senior colleagues in securing research grants to inaugurate what should be one of the most productive stages of their careers. Time spent submitting repeated grant applications is a distraction from the research endeavor itself and poorly utilizes the potential of this highly creative resource. Federal research-funding agencies, universities, and private foundations play an important role in nurturing early-career faculty and should take the following steps to support these researchers:

Recommendations for Federal Agencies

- Create or strengthen existing large, multiyear awards for early-career faculty.
- Pay special attention to early-career faculty during merit reviews of regular grant programs. Adopt career-stage-appropriate expectations for grant funding.
- Provide seed funding for early-career faculty to enable them to explore new ideas for which no results have yet been achieved.
- Develop policies responsive to the needs of primary caregivers, such as grant extensions or other appropriate support mechanisms.

Recommendations for Universities

- Develop or strengthen mentoring programs to encourage early-career faculty.
- Reconsider promotion and tenure policies for early-career faculty.
- Address the needs of primary caregivers.

Recommendations for Private Foundations

Historically, private foundations have played a pivotal role in filling the gap in funding for early-career researchers through dedicated programs. These initiatives are exceedingly valuable, but they can produce windfall effects. Private foundations should spread the wealth and cap the number of start-up and first awards made to a single investigator.

HIGH-RISK, HIGH-REWARD RESEARCH

Conservative thinking in agencies and during peer review discourages faculty from taking risks. "Don't put it in your grant unless you know it will work" too often guides early-career and established researchers. To remain competitive as a nation, it is critical that we pursue original and creative insights that have the potential to transform our knowledge, our economic well-being, and our quality of life. Federal research-funding agencies should enhance their support of high-risk, high-reward research in the following ways:

> "Don't put it in your grant unless you know it will work" too often guides early-career and established researchers.

Recommendations for Federal Agencies

- Consider targeted programs, grant mechanisms, and policies—and adapt existing grant programs—to foster transformative research; establish metrics with which to evaluate their success.
- Strengthen the application and review processes. High-risk research proposals face even greater challenges in a stressed peer-review system not equipped to appreciate them.
- Invest in program officers. They should be encouraged and expected to engage with the professional communities they fund. This requires an adequate administrative budget, which should not come at the expense of the research budget.

ISSUES COMMON TO EARLY-CAREER AND HIGH-RISK, HIGH-REWARD RESEARCH

Several broader aspects of the current federal funding environment impede the efforts of early-career researchers and stifle transformative research. At universities, complex and entrenched modes of operation exacerbate the problems. To address these issues, each could take the following steps:

Recommendations for Federal Agencies

- Establish new research programs only if they have enough critical mass to avoid fruitless grant-writing efforts. Grant programs that fund a very small percentage of applications are inefficient uses of money, time, and effort.

- Collect and analyze demographic data on applicants and principal investigators government-wide and in a uniform format to establish how well federal agencies support research. The current nonstandardized tracking among funding agencies hinders efforts to analyze funding trends.

Recommendations for Universities

- Accept greater responsibility for salaries of faculty members. Charging a portion of faculty salaries to research grants is necessary and appropriate, but the extreme model of expecting faculty to raise all of the funds for their own salaries, their students' stipends and tuition, and their research space puts a disproportionate burden on early-career faculty and discourages risk taking.
- Shoulder a larger share of the cost of new facilities and programs. As funds are raised to construct research buildings, campaign goals should include the continuing responsibility to maintain each facility and to support new programmatic activities.

CONCLUSION

America's research enterprise and its leadership role in scientific and technological innovation are being challenged. To adapt, we must invest in our future by nurturing early-career faculty and stimulating transformative research. Prompt action by all stakeholders—government, industry, universities, and foundations—is required. We believe that the recommendations outlined above constitute an effective place to begin.

Introduction

University research programs in science and engineering are essential to America's technological innovation, economic prosperity, health, national security, and quality of life. Following World War II, the United States made a commitment to sustain its world leadership by investing in university research and graduate education through a merit-based system of federal grants. The country has kept that commitment and, consequently, for many decades has led the world in science, engineering, technology, and higher education. American universities now perform intertwined missions of instruction, research, public service, and, increasingly, economic development.

America's leadership is being challenged as never before in the competitive arena of the new global economy and in the international research and education community as well. The American Academy of Arts and Sciences assembled a committee to study how well the mechanisms of federal funding of research are positioned to meet current and future needs. In the course of its analysis, the committee utilized data provided by the National Institutes of Health (NIH), the National Science Foundation (NSF), and the Office of Science at the Department of Energy (DOE); listened to first-hand experiences of early-career scientists; and spoke with leaders of both nonprofit and federal research-funding agencies. Although there are many concerns that are frequently voiced about federal research funding, the committee identified two issues critical to protecting the future of the science and technology enterprise; neither has received sufficient attention. They are (1) support for early-career faculty and (2) support for high-risk, high-reward potentially transformative research. America's commitment to invest in these two areas and to manage its investments effectively will impact directly how well it competes in the new global arena.

This committee's charge was to focus on modes of funding rather than levels of funding. We are deeply troubled, however, by two negative consequences of the currently tight funding environment: it adversely affects the development of early-career faculty and inhibits risk taking in research.

The nation needs to do a better job of attracting "the best and the brightest" to embark on careers as science and engineering faculty. Young scientists are needed for two reasons: (1) to ensure a sufficient number of U.S. researchers for the future, and (2) to increase the chances for fresh, pathbreaking ideas and transforming approaches to meeting twenty-first-century challenges to our economic vitality, environment, security, health care system, and way of life.

Yet, young scientists today face much greater burdens than in the past. They experience lengthening training periods in the form of multiple postdoctoral fellowships, limited pay, and greater hurdles to receiving federal funding. Although not the subject of this report, postdoctoral fellows and young research scientists face struggles similar to those of early-career faculty.[1] The executive and legislative branches have begun to recognize the need to nurture early-career researchers, and we encourage them to implement and strengthen support in this area.

Young scientists today face much greater burdens than in the past. They experience lengthening training periods in the form of multiple postdoctoral fellowships, limited pay, and greater hurdles to receiving federal funding.

Just as attracting tomorrow's talented scientists and engineers is imperative to ensure our nation's security and competitiveness, so too is investing in high-risk, high-reward research with transformative potential. Exploration of the unknown often produces surprising outcomes, and funding mechanisms need to encourage and embrace such research. Although many important advances are incremental, the occasional leaps in understanding inspire new fields. Thus, high-risk, high-reward research must be supported even though the rate of its progress will be uneven and the probability of success unknown.

Transformative is defined here as research with the potential to generate deep changes in concepts, to produce new tools or instrumentation that will allow the entire community to extend its reach, to create a new subfield, or to bring together different fields to make discoveries that would otherwise be impossible.

Although the United States remains the world leader in research and development, its leadership is eroding. The 2007

[1]See, for example, NAS/NAE/IOM (2000), NRC (2005a, b), and Davis (2006).

Georgia Institute of Technology study (Porter et al. 2008) of high-technology indicators, included in the NSF biennial report, *Science and Engineering Indicators*, ranks the United States second to China in the export of high-technology products. Constrained federal funding leads to overly conservative funding decisions. Although groundbreaking research continues, many researchers are discouraged from proposing high-risk studies in order to avoid critical reviews and to retain a steady funding stream. Most scientists and engineers believe that the peer review process, with all its merits, has an inherent bias against risk taking because a single critical review is sufficient to scuttle a proposal, especially when funds are limited. To remain competitive as a nation, we must pursue—in fact, inspire—original and creative insights that have the potential to transform our knowledge, our economic well-being, and our quality of life. As Albert Einstein said, "If at first the idea is not absurd, then there is no hope for it."

Constrained federal funding leads to overly conservative funding decisions.

THE GOAL

The goal of this white paper is to stimulate discussion of, and action on, two key issues essential to the nation's research enterprise. Regardless of overall levels of federal research investment, federal funding agencies and universities must now act to nurture early-career faculty and to stimulate and invest in high-risk, high-reward research that will lead science, technology, and the research enterprise itself into the future.

Although these topics are discussed separately in the first two sections, important relationships bind them. Major creative breakthroughs in science and engineering can occur at all career stages, but many flow from the contributions of talented early-career researchers. The experiences of researchers at the beginning of their careers color and shape their subsequent work. Researchers who achieve success early gain the confidence, professional reputation, and career commitment that enable them to continue to make important scientific and engineering contributions as their knowledge and skills mature.

Achieving success in the two target areas will require the integrated efforts of all stakeholders. We therefore offer comments and recommendations to government, universities, and private foundations, among others.

1 Early-Career Faculty

The United States invests substantially in the training of scientists and engineers through the completion of their Ph.D.s and MD/Ph.D.s.[1] Increasingly, this investment includes training greater numbers of women and minorities. Too often, however, we leave to chance the essential process of starting new doctorate holders on productive science and engineering research careers. This shortcoming is especially true in academia. The odds of getting started successfully seem to be diminishing even as the U.S. needs for fresh ideas that can advance the nation's future leadership and its prosperity in a more competitive world are growing. The barriers facing researchers at the beginning of their independent careers until tenure appointment need to be lowered through focused efforts that are well designed, managed, and coordinated to protect early-career researchers as much as possible from the annual fluctuations in the federal government's investment in research.

Although this report addresses mechanisms and priorities for federal funding of research, rather than budget levels, the two are linked. Our proposal for increased support of early-career faculty is not meant to suggest that support for established researchers is sufficient.

REASONS FOR CONCERN

Several trends merit the attention of policymakers, leaders of industry and universities, and the research community.

[1]The federal government spent $1 billion for fellowships, traineeships, and training grants in Fiscal Year 2005 (NSF 2007a).

Recent Trends: NIH

Research advances in the biomedical sciences have paved the way for unprecedented progress. The completion of the human genome project and the development of powerful new technologies such as those for gene expression profiling and for imaging biological systems are just two examples of far-reaching advances. Yet, as illustrated by the data below, intensifying competition for funds has especially disadvantaged early-career researchers.

> The odds of getting started successfully seem to be diminishing even as the U.S. needs for fresh ideas that can advance the nation's future leadership and its prosperity in a more competitive world are growing.

- Early-career investigators are waiting a long time to receive their first grant. The average age for first-time awardees of NIH's primary research grants, R01-equivalent grants,[2] is 42.4, an increase from the average age of these investigators in the 1980s and 1990s*. The increase in age for first-time NIH grantees is due to two components: increased training time and increased time between first independent position and first grant. See Table 1-1.
- The funding rate[3] for new investigators lags that of established investigators who have previously received NIH funding. In 2007, the overall funding rate for all applicants of R01-equivalent awards was 23.6 percent. For new investigators, the funding rate was 20.6 percent; for established investigators submitting new applications, the funding rate was 23.8 percent.[4]*
- Since 1980 the share of R01-equivalent grants awarded to first-time investigators has declined steadily from nearly 33 percent in 1980 to less than 25 percent in 2006. Even during the doubling of the NIH budget, the overall proportion of R01-equivalent grants awarded to new investigators remained essentially constant. See Figure 1-1.
- Although the proportion of grants did not increase as the NIH budget doubled, the absolute number of investigators receiving their first R01-equivalent grant grew from a predoubling level of 1,483 in 1997 to 1,695 in 2003. The number of investigators declined from 2003–2006 but increased to 1596 in 2007.*

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[2]R01-equivalent grants include R01 and R37 grants. Historically, R01 grants also included R23 and R29 grants, which now no longer exist.

[3]Funding rate is defined as the number of awards divided by the number of submitted proposals.

[4]Data as of December 4, 2007, provided by NIH.

*The numbers have been amended to reflect revised data provided by the NIH on August 29, 2008.

TABLE 1-1

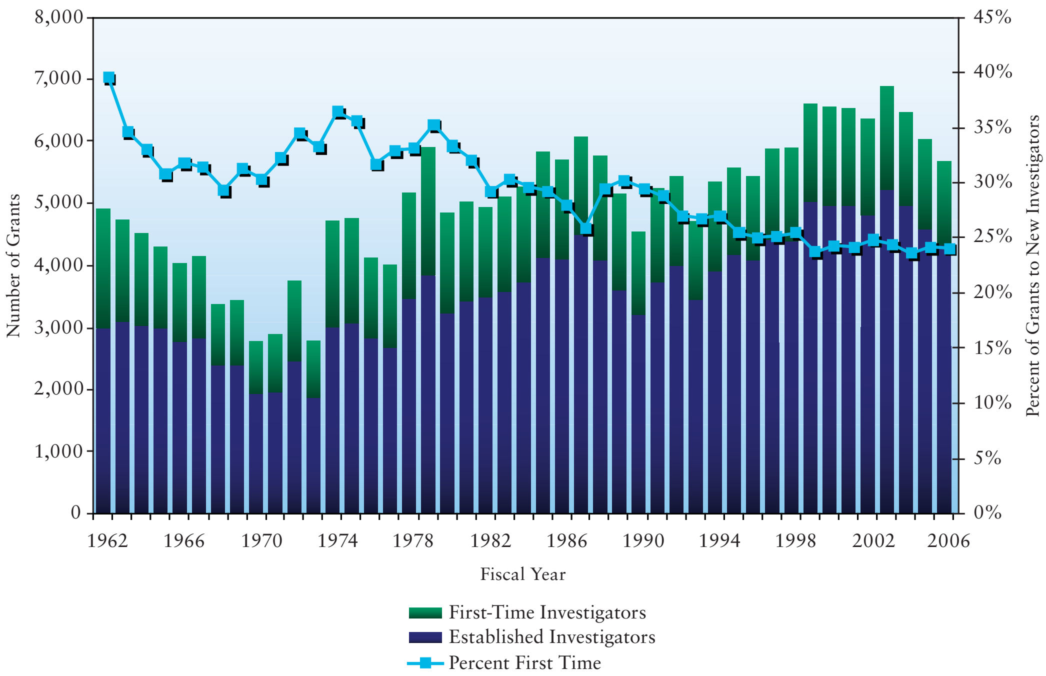
Demographic Changes in Medical School Faculty and NIH Principal Investigator Pools from 1980 to 2006

	1980	1998	2006
Number and Average Age of NIH PI	14,887	17,761	25,419
	39.1	42.7	50.8
Number and Average Age of NIH New PI	1,843	1,355	1,346
	37.2	39.0	42.4
Number of Medical School Faculty Positions	53,552	73,413	121,468
Average Age of Medical School Faculty	43.1	45.2	48.7
Average Age of First-Time Assistant Professors	33.9	35.4	37.7

An aging medical school faculty from 1980 to 2006 is reflected in NIH principal investigators pool. The average age of first assistant professorship is 37.7, and the average age of first NIH award is 42.4. SOURCE: Presentation to the American Academy of Arts and Sciences's Committee by Norka Ruiz Bravo, NIH Deputy Director for Extramural Research, National Institutes of Health, September 21, 2007.

FIGURE 1-1

Number of Research Grants Awarded by NIH from 1962 to 2006



The number of R01-equivalent grants given to first-time investigators (green) versus established investigators (dark blue) is shown. The light blue line represents the percentage of all R01-equivalent grants awarded to first-time investigators. The percentage going to first-time investigators has both decreased and increased since 1962, but it has generally declined since 1990. SOURCE: NIH 2007c.

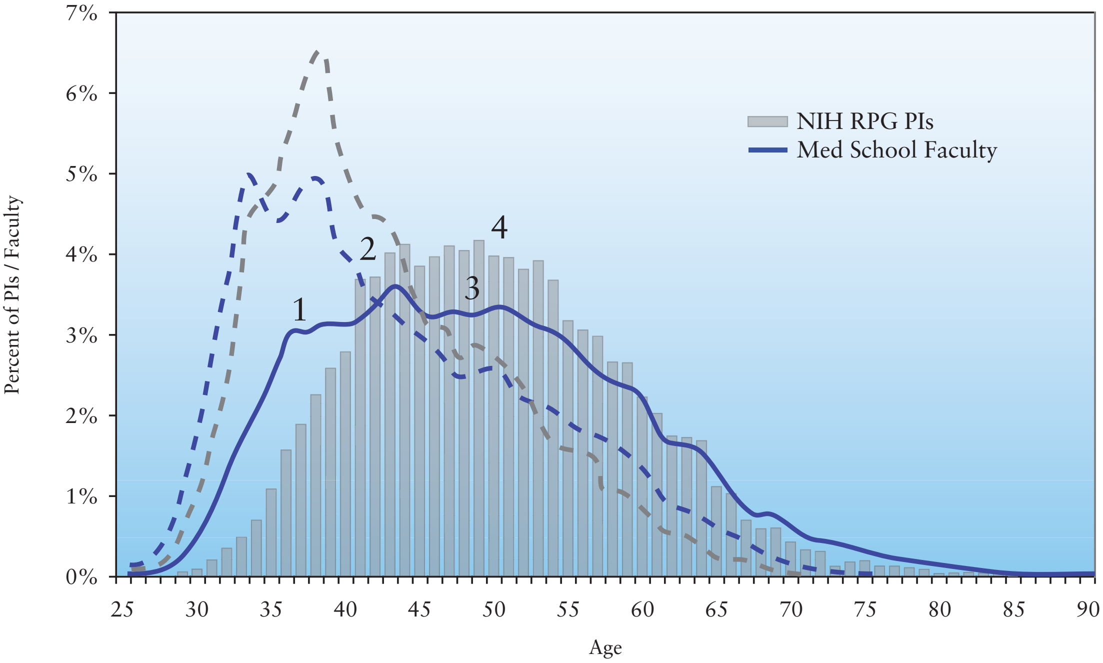
- The number of times new investigators must submit proposals before receiving funding has increased. Today the majority of first-time investigators receive their grants only after resubmitting them at least once. In 1980, 86 percent of new investigators received their grant on their first submission; in 1990 and 2000, about 58 percent to 59 percent did so; in 2007, the figure had fallen to 28 percent. See Table 1-2.
- Medical schools receive about 55 percent of NIH extramural research funding.
- Between 1980 and 2006, the average age of NIH principal investigators increased dramatically, in part reflecting a similar shift in medical school faculty age over the same period. See Figure 1-2 and Table 1-1.
- The number of medical school faculty positions more than doubled from 53,552 to 121,468.
- The average age of medical school faculty increased by 5.6 years to 48.7.
- The average age of first-time assistant professors increased by 3.8 years to 37.7.

TABLE 1-2
Number of Amendments to NIH R01-Equivalent Grants to First-Time Investigators

	Competing Awards Made to First-Time Investigators								
		Number Funded on				Percent Funded on			
FY	Total	Original	First (A1)	Second (A2)	Third or later (A3+)	Original	First (A1)	Second (A2)	Third or later (A3+)
1980	1,731	1,492	216	21	2	86.2	12.5	1.2	0.1
1990	924	535	281	91	17	57.9	30.4	9.8	1.8
2000	1,716	1,013	532	169	2	59.0	31.0	9.8	0.1
2007	1,633	453	674	503	3	27.7	41.3	30.8	0.2

The majority of first-time investigators receive their grants only after resubmitting them at least once. In 2007, less than 30 percent of grants to first-time investigators were awarded on their first attempt, compared to 1980 when 86 percent of grants to first-time investigators were awarded on their first attempt. Resubmitted proposals with amendments (A) are A1 (amended once), A2 (amended twice), and A3 (amended three or more times). SOURCE: Data as of January 25, 2008, provided by NIH.

FIGURE 1-2
Age Distribution of Medical School Faculty and NIH-Funded Principal Investigators in 1980 and 2006



The age distribution of NIH-funded principal investigators (represented by gray bars and line) closely models that of medical school faculty (represented by the dark blue lines). In addition, there has been a dramatic shift to older ages for both the NIH principal investigators and medical school faculty from 1980 (represented by the dashed gray and dark blue lines, respectively) to 2006 (represented by the gray bar graph and solid dark blue line). In 2006 the average of NIH-funded principal investigators was 50.8 (4), similar to the average of medical school faculty 48.7 (3). For the same time period the average age of first assistant professors was 37.7 (1), but the average age of new principal investigators at NIH was 42.4 (2).
SOURCE: Data from NIH 2007a.

- The population of non-tenure-track faculty in medical schools has grown. In 1993, 33 percent of medical school faculty were in non-tenure-track positions; following the doubling of the NIH budget in 2003, 45 percent were.[5] Moreover, the majority of non-tenure-track faculty members are assistant professors.[6]

[5]http://www.nber.org/sewp/Early%20Careers%20for%20Biomedical%20Scientists.pdf.

[6]Even though the data collected by the Association of American Medical Colleges (AAMC) on tenure status remains incomplete, it is clear that assistant professors will still represent the majority of nontenure faculty. AAMC Faculty Roster. http://www.aamc.org/data/facultyroster/reports.htm.

Recent Trends: NSF[7]

The National Science Foundation is experiencing pressures and strains similar to those of NIH. Congress passed and President Bush signed the America COMPETES Act. The Foundation's FY 2009 budget proposal includes initiatives to strengthen investment in physical sciences and engineering research and to strengthen opportunities for early-career faculty. Such continued cooperation will be essential if the country is to address successfully the issues posed by current trends, several of which were documented by the report, *Impact of Proposal and Award Management Mechanisms* (IPAMM; NSF 2007b).

- The average time since last degree for all principal investigators at NSF has increased modestly. In 1980, the average time since degree was 14 years. In 2006, it was 16.6 years. See Table 1-3.

- The average time since degree for first-time principal investigators at NSF also increased between 1990 and 2006. In 1990, it was 8.5 years, and it increased to 9.3 in 2006 (Table 1-3). In 2006, the average age of doctorate recipients in the life sciences, physical sciences, and engineering was 30 to 31 (NSF 2006). Put these two numbers together and the average newly minted doctorate will not receive her or his first NSF award until age 39 to 40, with the median age 37 to 38.

- While funding rates at NSF have decreased for all investigators, the funding rate for new investigators is significantly below that of previously funded investigators. Overall, funding rates decreased from 30 percent in 2000 to 21 percent in 2006. Funding rates for new investigators decreased from 22 percent to 15 percent during that period. The funding rates for established investigators fell from 36 percent in 2000 to 26 percent in 2006 (NSF 2007b).

- Since 1990, the proportion of research grants awarded annually to new investigators has remained about 30 percent.[8]

[7]The data that follow for NSF are for all research grants, including early-career grants.
[8]Data provided by NSF.

TABLE 1-3
Elapsed Time Since Last Degree for NSF Principal Investigators

	1980	1990	2000	2006
All principal investigators				
Number of awards	5,200	5,791	6,498	6,714
Funding rate (%)		30	30	21
Mean years since degree	14	15.2	16.3	16.6
Median years since degree	12	13	14	14
First-time investigators				
Number of awards	n/a	1,777	1,845	1,901
Funding rate (%)		19	22	15
Mean years since degree	n/a	8.5	9.1	9.3
Median years since degree	n/a	5.5	6.5	6.5

First-time investigators are waiting longer to receive their first grant from NSF. The time since last degree has risen for all NSF-funded investigators, including first-time investigators. SOURCE: Data provided by NSF.

- While 70 percent of new NSF investigators received their first award within seven years of their degree, the distribution of when they received their first award has shifted. In 1990, 30 percent of awards to new investigators were awarded to investigators within three years of their degree, but in 2006 only 18 percent were awarded to investigators within three years of their degree (Table 1-4).
- One-half of new investigators never again receive NSF funding after their initial award. For new investigators who received awards in 1995 and 2000, 50 percent or fewer still had NSF funding three years after the initial award, with three years being the typical length of NSF grants. Four years later, only 40 percent still held NSF funding. The number slowly declines with each additional year from the initial award. The data do not track whether these investigators found alternative funding sources, but the marked decline suggests that some, perhaps many, new investigators do not secure a second grant to sustain their research (NSF 2007b).

TABLE 1-4
Cumulative Distribution of Years Since Last Degree for First-Time NSF Investigators for 1990, 2000, and 2006

Years Since Degree	Cumulative Distribution of Awards in Years Since Degree (%)		
	1990	2000	2006
1	8.66	3.68	3.75
2	17.98	10.77	10.82
3	29.25	20.07	18.05
4	38.18	29.42	27.70
5	46.97	38.15	39.18
6	54.27	47.00	47.19
7	59.61	54.31	54.75
8	63.97	60.09	60.60
9	67.95	65.25	65.62
10	71.86	70.52	70.70

From 1990 to 2006, two-thirds of first-time investigators received their awards within nine years of their last degree. In 1990, however, nearly 30 percent of investigators received their award within three years of their degree; by 2006 only 18 percent had. SOURCE: Cumulative distributions are calculated on the basis of data provided by NSF.

- New investigators now spend more time preparing more proposals than experienced investigators. New investigators are submitting double the number of proposals submitted by more established investigators. From 1997 to 2006, new investigators accounted for 40 percent of proposals received, even though they accounted for only 22 to 24 percent of the principal investigators submitting proposals (NSF 2007b).
- More than half of new investigators require two or more attempts before they receive funding.[9] For resubmitted proposals, the data do not distinguish the number of times a proposal has been amended.

[9]Data provided by NSF.

- New investigators receive smaller awards on average than established investigators. In 2007, the average award for new investigators was $116,151, with a median of $99,578, whereas the average for prior investigators was $156,249, with a median of $117,878.[10]

Other Agencies

Other federal departments and agencies that invest in research, such as the Office of Science at the Department of Energy (DOE), the Department of Defense (DOD), and the National Aeronautics and Space Administration (NASA), do not track demographic data on their applicants. Therefore, the committee could not analyze those agencies' funding trends for this report. The DOE Office of Science recognizes the need for such information and is considering new data systems for tracking it.

Tracking Demographics of Early-Career Researchers

Although NIH and NSF collect data on early-career investigators and other agencies recognize the need for such data, better demographic tracking is required. No agency currently tracks an individual.

Many graduate students and postdoctoral fellows are supported by NIH and NSF funding, but we do not know what happens to these individuals after their training. Nor do agencies know what happens to early-career investigators after their first award. If such tracking were done by all agencies, policymakers and program managers could ascertain whether these new investigators receive future/additional funding from other funding sources.

Key questions cannot be answered because no agency has collected certain critical information, such as the size of the early-career pool. For instance, how many doctoral researchers each year leave academic research, and how many remain? How many remain in academic research and go unfunded? Federal agencies record information only on researchers who apply for funding. Obviously, recipients of doctorates follow a diversity of career paths, including industrial and government positions, and so there is no expectation that most should stay in academic research. Yet without the data, agencies cannot analyze or understand how well they are supporting early-career researchers.

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[10]Data provided by NSF.

Award Programs for Early-Career Investigators

Federal funding agencies have a number of award programs for early-career researchers.

Agency	Name of Grant	Code	Applications	Awards	Description
DOE	Outstanding Junior Investigator (OJI) Program in High-Energy Physics			5 to 10	The purpose of this program is to support the development of individual research programs by outstanding scientists early in their careers. Applications should be from tenure-track faculty investigators who are currently involved in experimental or theoretical high-energy physics or accelerator physics research, and should be submitted through a U.S. academic institution. In the recent past, awards have averaged $70,000 per year.
DOE	Outstanding Junior Investigator (OJI) Program in Nuclear Physics			3 to 5	The purpose of this program is to support the development of individual research programs of outstanding scientists early in their careers. Applications should be from tenure-track faculty who are currently involved in experimental or theoretical nuclear physics research, and should be submitted through a U.S. academic institution.
NIH	NIH Director's New Innovator Awards	DP2	2,154*	31*	This award supports highly innovative research projects by new investigators in all areas of biomedical and behavioral research.
NIH	NIH Pathway to Independence Award	K99/ R00[a]	1,000	150 to 200	The principal investigator award will provide up to 5 years of support consisting of two phases. The initial phase will provide 1–2 years of mentored support for highly promising, postdoctoral research scientists. This phase will be followed by up to 3 years of independent support contingent on securing an independent tenure-track or equivalent research position. The principal investigator award is limited to postdoctoral trainees who propose research relevant to the mission of one or more of the participating NIH Institutes and Center.
NIH	Mentored Research Scientist Development Award	K01[a]			This award supports career development in a new area of research for 3–5 years; salary is determined by the sponsoring Institute.
NIH	Career Transition Award	K22[a]			This award supports an individual postdoctoral fellow in transition to a faculty position.
NIH	Research Project Grant Program	R01			See "New Investigator Program NIH Institute and Center Practices."
NSF	NSF CAREER—Faculty Early-Career Development Program		2,600	400	This program is a foundation-wide activity that offers the NSF's most prestigious awards in support of the early-career-development activities of those teacher-scholars who most effectively integrate research and education within the context of the mission of their organization. There is an eligibility requirement that applicants can submit only one CAREER proposal per annual competition, and many participate in a total of three CAREER competitions.
Office of Naval Research (ONR)	Young Investigator Program			27	The objectives of this program are to attract to naval research outstanding new faculty members at institutions of higher education, to support their research, and to encourage their teaching and research careers. Awards of up to $100,000 per year for 3 years, with the possibility of additional support for capital equipment or collaborative research with a Navy laboratory, are made, based on research proposals and supporting materials. Special attention will be given to proposals in naval priority research areas listed in the announcement.

[a] *These K awards are included because a portion of the awards covers the early-faculty period.*

* *The numbers have been amended to reflect revised data provided by the NIH on August 29, 2008.*

Summary

Early-career researchers, the data show, are facing greater difficulty than in the past and greater difficulty than more senior researchers in getting research grants to inaugurate what should be one of the most productive stages of their careers. The difficulty in receiving an initial grant creates both immediate and far-reaching problems. As a practical matter, faculty now must spend a great deal of time submitting repeated grant applications, a distraction from the research endeavor itself. Of equal concern, many are frustrated by their limited productivity. The low morale of these new faculty is likely to be communicated directly or indirectly to their students. This is, therefore, not just a problem confronting the new researchers, but the nation as well. The future prosperity of the United States will depend, in part, on having a healthy, creative research enterprise. Discouraging bright students from becoming researchers and preventing those who persevere from pursuing their most daring ideas are not good strategies for building the nation's future.

The future prosperity of the United States will depend, in part, on having a healthy, creative research enterprise.

RECOMMENDATIONS TO GOVERNMENT

Funding for early-career scientists should be made a priority government-wide. All departments and agencies that invest in research should establish policies, research programs, and management mechanisms designed specifically to support early-career faculty in tenure-track or equivalent positions.

Mission agencies, such as DOE, the National Institute of Standards and Technology (NIST), and NASA, have an equal stake in ensuring a continuing supply of talented researchers to advance their missions. Unlike universities, independent start-up funds in most agency laboratories are very difficult to obtain, and early-career scientists typically have to join a group led by a more senior scientist. It is important that individual genius can still be nurtured in the setting of a federal laboratory, even if the main focus of that laboratory is to tackle problems of a size and timescale that would present challenges to an individual principal investigator.

The FY 2009 budget request for NSF seeks to strengthen its initiatives for early-career faculty through an 8 percent increase in funding for early-career development. The committee commends this leadership and urges Congress and all executive branch departments and agencies that invest in university research to make sustained funding for early-career scientists a priority.

Agencies and departments that invest in university research also should track the demographic characteristics of their researcher communities and identify promising young faculty across the life sciences, physical sciences, and engineering, as NIH and NSF have begun to do. Interagency coordination will be essential to facilitate this effort.

Departments and agencies such as DOD, DOE, and NASA will need policy guidance and funds to create initiatives for early-career scientists tailored to the fields of science and engineering that support their missions. Needs and programmatic details will vary by field and therefore by department and agency.

Agencies and departments that invest in university research should track the demographic characteristics of their researcher communities. Interagency coordination will be essential.

1. Create Targeted Grant Programs for Early-Career Faculty

Each federal research agency should have a program dedicated solely to funding early-career faculty. Early-career-faculty members have many demands placed upon them. They also have less experience and fewer prior accomplishments than their more senior colleagues, making it harder for them to compete for funds. Thus, grants targeted to these faculty should be evaluated more on the potential of the individual and less on the perceived probability that the project's aims will all be met, as long as the project is well conceived.

Grant programs should be flexible and designed to meet the particular needs of early-career tenure-track faculty.[11] Budding researchers are best served by large, multiyear awards—onetime grants of five- or six-year duration that are sufficient to carry the faculty member through her or his tenure decision, similar to NSF's CAREER awards. Such awards should include a level of funding sufficient to support at least two graduate students or technicians and a minimal level of paperwork and reporting requirements.

In early-career programs, agencies should assess an application on the basis of the applicant's early track record and research plans rather than preliminary data as an independent investigator. Funding should provide the new faculty member with the flexibility to reallocate funds and request increments as research progresses.

[11]The terms "faculty" and "tenure decision" are used here and throughout the report for brevity. In many cases it is appropriate that similar programs and policies be available to beginning investigators employed by nonprofit research institutes and government centers and laboratories. If these positions are untenured, the funding should be of sufficient size and duration to carry the investigator through the first major renewal of his or her appointment.

Agencies should establish a target funding rate of at least 25 percent of such applications in each round. This will enable them to have immediate positive impact both on the aspirations of early-career faculty who now struggle and on the vitality of the disciplines that are the foundation of their national missions.

2. Pay Special Attention to Early-Career Faculty in Merit Review of Regular Grants

For at least two reasons, programs that are not exclusively open to early-career faculty must take additional steps to ensure that such faculty members are not "lost in the shuffle." First, not all early-career faculty will apply to, or receive grants from, dedicated early-career research programs. Second, these new faculty members often face their greatest hurdles when they apply for their second grants, regardless of whether they received early-career awards. At NSF, for example, only 40 percent of first-time investigators have NSF funding four years after their first award, which is generally granted for a period of three years. If the nation wants a steady stream of talented new faculty with fresh ideas to become established researchers, the merit review processes must pay special attention to their applications and adapt processes to their needs and limitations. As in the targeted grant programs, the evaluation of first- and second-time investigators in the regular grant programs should be based to a significant extent on the broader accomplishments and potential of the individual in addition to the potential impact of the project.

Agencies should allow applicants to check a box indicating whether they are a new investigator (have not been a principal investigator on any major grant) or are applying for a second award (previously a principal investigator on a single major federal grant). Researchers who have received an early-career award could check the "second award" box the first time they are in the regular pool of applicants, assuming that the prior early-career award was sufficient in size and duration as outlined in the recommendation above.

In regular grant programs (those not dedicated exclusively to early-career scientists), federal agencies should treat early-career applicants, including first- and second-time investigators, differently from other applicants in at least the following ways:

a. Agencies should not require preliminary data on their applications. The application should be brief, focusing on the potential of their ideas and on their potential as researchers.

b. Agencies should not reject proposals solely on the grounds that the proposed work is "overly ambitious."

c. Agencies should require that all proposals from early-career applicants receive a full review and not be set aside as unworthy of review, as is currently a possible outcome.

d. Agencies should provide written comments on all proposals from early-career applicants.

e. Agencies should allow early-career applicants to reapply rapidly if a problem with their proposal is easy to address.

f. Agencies should consider establishing a "predecision rebuttal" system through which reviewers provide early-career applicants, prior to the formal meeting of a review group, a brief summary of the assessment of the technical aspects of the application. The applicant should then be invited to submit a short predecision rebuttal that clarifies ambiguities or corrects reviewer misconceptions or errors.

Merit review processes need to take into consideration that early-career faculty, by definition, cannot point to a long string of previous research successes, cannot have large amounts of preliminary data, and often are not yet highly skilled in writing proposals.

These recommendations are drawn from discussions with successful young faculty who described the difficulties they faced as they entered competition in the current system.[12] Merit review processes need to take into consideration that early-career faculty, by definition, cannot point to a long string of previous research successes, cannot have large amounts of preliminary data, and often are not yet highly skilled in writing proposals. At the same time, these individuals often have great potential, new ideas, and new techniques—traits that are exactly what the country now needs in our research system but too often are overlooked or undervalued by current programs and merit review processes.

3. Create Seed Funding Programs for Early-Career Faculty

Seed funding can be instrumental in enabling early-stage researchers to explore a new idea for which no results have yet been achieved. Then, if technical hurdles are overcome or

[12]See also *A Broken Pipeline?* (2008).

some promising preliminary results are achieved, the work becomes competitive for funding in the regular grant system. Seed grants can be shorter in duration and more modest in budget than regular research grants, and nonrenewable. In addition to considering freestanding seed grant programs for early-career faculty, agencies should also consider seed funding added on to existing grant awards. That is, if in the course of a funded research project, an early-career investigator makes an unexpected and highly exciting finding that is tangential to the funded research, there could be a rapid mechanism to support further investigation of the new area without going through the entire peer-review process.

4. **Develop Policies for Primary Caregivers**

   Time taken off by primary caregivers, the majority of whom are women, can be especially difficult for early-career investigators. Funding agencies, together with universities, should develop policies and mechanisms to provide grant extensions or other appropriate support mechanisms for childbirth and child care. Consistent policies across agencies are desirable.

RECOMMENDATIONS TO OTHER STAKEHOLDERS

Other stakeholders, particularly universities and private foundations, also should adopt policies and practices designed to nurture early-career faculty.

Recommendations to Universities

1. **Actively Mentor Early-Career Scientists**

   It is in the best interest of universities to support and mentor their junior faculty in whom they make substantial investments. University senior faculty have the expertise, indeed the responsibility, to provide effective mentoring.

   - Research institutions should develop formal mentoring programs for junior investigators to provide support and training in all aspects of the practice of science and engineering, including the development and writing of grant and contract proposals. Institutions also should develop mechanisms, which could include awards or other forms of recognition, to encourage better mentoring both informally and in formal programs. An institutional official (e.g., dean, vice dean for research) should be prepared to document and certify the institutional program in response to requests or requirements from granting agencies.

- Senior faculty members should serve as mentors to their junior colleagues. Effective mentoring will result in more successful hiring of top candidates, and enhance the reputations of departments and institutions.

- Research institutions should undertake rigorous self-examination of the institution's cultural dynamics for early-career researchers, especially women and members of minority groups. If barriers of bias and isolation among women and minorities are to be overcome, senior administrators and academic officers must lead and apply the lessons and insights of experience.

2. Revise Promotion and Tenure Policies

Universities should strengthen their promotion and tenure policies for early-career faculty by doing the following:

- Review personnel systems and criteria for tenure and promotion to ensure that early-career tenure-track faculty who participate in groups or teams receive due credit for their contributions to collaborative research projects. Because promotion and tenure decisions rely heavily on letters from outside experts who may not have the information to assess a faculty member's contribution to a team effort, input from colleagues within the institution must be sought and included in the evaluation.

- Encourage early-career faculty to pursue their best ideas and to take risks. During tenure and promotion decisions, do not penalize them for negative results from a well-conceived research plan.

- Reward quality over quantity when evaluating publications. For tenure review, request only a few best papers and a few most recent, together with a self-assessment of the significance of the work.

- Recognize and reward service to the scientific community, including participation in peer review. In addition to infusing the community with contemporary knowledge of research questions, such service can be an important professional development experience for the faculty member.

3. Consider the Needs of Primary Caregivers

Many universities are beginning to recognize the importance of offering trustworthy, convenient, and affordable child care to young parents as they establish their research careers. Many universities have also instituted tenure and promotion policies for primary caregivers, such as the option to stop the clock for tenure. Going forward, universities together with funding agencies should develop policies and mechanisms to provide extensions on research funding or other appropriate support mechanisms for childbirth and child care, including stipends for child care while primary caregivers are away from home for activities related to professional development.

It is in the best interest of universities to support and mentor their junior faculty in whom they make substantial investments.

Recommendations to Private Foundations

Private foundations have played a pivotal role in funding many early-career researchers. Where gaps in funding occur, private foundations have been quick to address them through special programs.[13] A number of private foundations offer generous awards to early-career researchers; however, the resources of these foundations are limited and cannot be expected to fill this need entirely.

Spread the Wealth

Targeted, early-career funding programs are exceedingly valuable, but they can produce windfall effects. A promising early-career scientist who has received one early-career award is more likely to receive additional awards. Some private foundations have capped the number of start-up and first awards a single investigator may hold. Such a limit should be considered by all private foundations.

[13]On March 10, 2008, the Howard Hughes Medical Institute announced a new $300 million program to nurture as many as 70 early-career scientists across a broad range of fields relevant to biological and medical inquiry. The new program offers six-year grants to researchers who are at a critical point in establishing their own vibrant, independent research programs, similar to the multiyear awards recommended above.

2

High-Risk, High-Reward Research

The progress of science and engineering research is often iterative, moving ahead step-by-step, building on previous discoveries. Such research is essential, and unexpected breakthroughs can sometimes result from such investigations.

Science also benefits greatly from work that has the potential to disrupt complacency and conventional thinking—innovation in methods, instruments, and software and paradigm shifts. When funding is tight, however, reviewers and program officers have a natural tendency to give highest priority to projects they deem most likely to produce short-term, low-risk, and measurable results. Our nation's research portfolio now needs to be rebalanced. Investments in projects with the potential to transform our understanding of the world by leading to the development of radically new science, engineering, and technology need to be increased, even though these endeavors often carry a high risk of failing to achieve the expected outcome.

> Science benefits greatly from work that has the potential to disrupt complacency and conventional thinking—innovation in methods, instruments, and software and paradigm shifts.

The dynamics of research identified as high-risk, high-reward that is potentially transformative are not easily described. Definitions of such research vary, and they lack precision. Such research, however, would have the potential to generate deep changes in concepts, or to produce new tools or instrumentation that will allow the entire community to extend their reach, or to create new subfields of science, or to bring together different fields to make discoveries that would otherwise be impossible.

The National Science Board asked the National Science Foundation to adopt the following definition of transformative research:

[R]esearch driven by ideas that have the potential to radically change our understanding of an important existing scientific or engineering concept or leading to the creation of a new paradigm or field of science or engineering. Such research also is characterized by its challenge to current understanding or its pathway to new frontiers. (National Science Board 2007, p. 10)

Because potentially transformative research pushes beyond the boundaries of what is known or accepted, the probability of failure is significant. In fact, if a program invests mostly in proposals that end up meeting all their goals, one must question whether the program is truly fostering high-risk, high-reward research.

When funding is tight, reviewers and program officers have a natural tendency to give highest priority to projects they deem most likely to produce short-term, low-risk, and measurable results.

There can be multiple pathways to paradigm-shifting discoveries. Many arise from the unexpected rather than a rigid adherence to a directed approach. Few pioneering research projects ever proceed as anticipated. Creative researchers need to be trusted to overcome challenges as they arise. Research grant mechanisms must empower rather than inhibit creative thought and the pursuit of unexpected findings. Special programs to support emerging, untested but potentially breakthrough ideas are needed as well as enhanced tolerance for unanticipated new directions within ongoing programs. Several funding agencies have taken steps to develop such programs (i.e., the Pioneer Award at NIH and the Transformative Research Initiative at NSF).

A TROUBLING CONSENSUS

Many researchers believe that federal agencies systematically shy away from high-risk projects. In the worst-case scenario, scientists stop even proposing such projects, leaving the agencies with nothing but more conservative proposals from which to choose. Agencies need to address these concerns more seriously.

Some funding agencies, notably NSF, have attempted to reduce competitive pressures by increasing grant size and duration, but the size of an NSF award frequently is still too small to sustain a single researcher's laboratory equipment, students, and staff. Multiple awards from several sources remain the norm. Continued survival in such a system requires that the researcher demonstrate "progress" in each of his or her multiple projects, which means having some reasonable guarantee that each project will produce publishable results.

A 2007 NSF survey of investigator attitudes about transformative research revealed that while more than 56 percent of researchers who responded believe "to a great or moderate extent" that NSF welcomes transformative research proposals, over half found little transformative research among the proposals they had reviewed (NSF 2007b).

As the resulting constant hunt for dollars fosters conservative thinking, it also impedes the pace of research. The thought, "Don't put it in your grant proposal unless you know it will work," too often guides senior and junior faculty alike as they compete in an intense national grant-writing mill.

Historically, the DOD, the DOE, and industrial laboratories of the past have taken a longer term view of science funding than the NSF. As a result, the longer term scientific research support needed to develop the maser, the laser, and the transistor did not come from NSF funding but from ONR, the Air Force Office of Scientific Research, and AT&T. Quantum mechanics, a seemingly abstract field without apparent practical application, was necessary before we could invent the transistor and lasers that led to computers and the Internet. Decades after it was discovered, x-ray diffraction allowed the unraveling of the molecular structure of DNA and proteins, essential information for the development of modern molecular biology and the biotechnology industry that followed. In the past two decades, research directed to longer term missions has greatly diminished in industry, DOD, and DOE. The U.S. research and development portfolio must include the support of long-term, potentially transformative research that will be needed to establish the scientific foundations for the next new industry.

In the preface to his book, *I Wish I'd Made You Angry Earlier,* Chemist and Nobelist Max Perutz writes:

> *Creativity in science, as in the arts, cannot be organized. It arises spontaneously from individual talent. Well-run laboratories can foster it, but hierarchical organization, inflexible, bureaucratic rules, and mounds of futile paperwork can kill it. Discoveries cannot be planned; they pop up, like Puck, in unexpected corners.* (Perutz 1998, p. ix)

Examples of Transformative Research

Historical Examples of Transformative Research:

- **The transistor and quantum mechanics. The vacuum tube was developed to make transcontinental telecommunications possible, but by the 1930s, it was clear that a more reliable electronic component was needed. Scientists at Bell Laboratories began a concerted effort to invent the transistor. It is important to realize that this project would not have even been started without quantum mechanics, our most fundamental and transformative theory of the atomic world. The new theory enabled us to understand how electrons move in metals, in semiconductors, and in the boundaries between different materials. These transformative ideas led to the groundbreaking research to create the first transistor in 1947, which in turn laid the foundations for present-day telecommunications, semiconductor, computer, and Internet industries.**

- **Angiogenesis (the formation of new blood vessels). Dr. Judah Folkman's early proposals—that tumors could not grow to significant size without a blood supply and that they secreted a signal molecule to attract new blood vessels—were met with skepticism. Today, however, the concept of angiogenesis is textbook material, and antiangiogenic pharmaceuticals provide successful treatments for macular degeneration and a promising approach to cancer therapy.**

Current Examples of Transformative Research: A number of universities are providing internal funds to encourage and support transformative research. The program at the University of California at San Francisco is called Sandler Blue Sky Awards. On average, the institution confers about one award every two years. The following three projects are recent Blue Sky Awardees.

- **How cells tell direction. There are many situations in which cells must choose and maintain a single direction to follow during a migration process. Understanding how cells carry out these directed movements has potential applications in facilitating wound healing and nerve regeneration. Centrosomes and cilia are cellular organelles whose positions or conformations have long been correlated with the direction of migration, but whether these correlations reflect cause or effect is unknown. This proposal seeks to resolve that issue by a direct test in which microscopic magnets would be affixed to one or the other organelle; those organelles would then be directionally deflected by** applying a magnetic field and testing whether migration direction follows. To carry out this test, numerous technological hurdles must be overcome, for example, to attach the micromagnets selectively and tightly to the organelles, to determine and achieve sufficient magnetic force to deflect organelles within living cells.

- Repair of injured axons. Spinal cord injuries incapacitate victims and exact a great societal burden. Current efforts to promote recovery focus on stimulating nerve regeneration from the site of injury back to the original targets. This proposal seeks instead to develop a microsurgery strategy in which damaged regions of individual neurons are excised and replaced by healthy donor segments to reestablish neuronal connectivity and function. To succeed requires development of technology and fabrication of microdevices for nerve cutting, precise alignment of specific neuron segments, and efficient and specific fusion of the aligned ends.

- Complex system kinetics. Understanding fully the logic of cellular "operating systems," or the ways that a drug works within an intact organism, will eventually require metabolic and genetic flow diagrams that include concentrations of components and reaction rate behaviors that fail to follow conventional laws of diffusion and mass action. Developing a theoretical basis to describe the kinetics underlying complex systems has the potential to revolutionize drug discovery for important diseases such as cancer and cardiovascular diseases. Whereas experimental biologists seek to extend single-component or single-reaction studies into qualitative depictions of cross-talk nodes or networks, this theoretical study seeks to derive a quantitative description of complex systems even in the face of large numbers of unknown quantities. To do so requires nothing less than the development of new principles of kinetics, and this proposal would test the robustness of those principles by applying them to well-described biological systems, such as the calcium signaling network in cardiac muscle cells.

NIH PIONEER AWARDS

With the goal of promoting potentially transformative research, NIH established the Pioneer Award program. The NIH leadership described such research as "ideas that have the potential for high impact, but may be too novel, span too diverse a range of disciplines, or be at a stage too early to fare well in the traditional peer review process."[1] Although the program is still young and a full assessment of its impact is premature, it is already clear that the program is too small to meet the research community's desire to engage in potentially transformative research. In the first year of the program (2004), 9 of 1,300 applications were funded, a 0.69 percent funding rate. Once the low probability of funding became known, many researchers became discouraged and did not reapply. As a result the number of applications dropped in the subsequent years to approximately 800, 400, and 400, respectively. The funding rate has remained very low, in the range of 1.6 to 4 percent.

The gestation period for transformative outcomes and the time required to understand their impact and importance can be very long.

Because of low funding rates, many proposals with the potential to make a transformative impact on the biomedical sciences have gone unfunded. There are other adverse consequences as well. The low funding rate leads to low morale. Such a system is also costly and inefficient. The administrative costs of announcing the competition, reviewing the applications, and flying reviewers to Washington to interview the finalists are amortized over a very small number of funded grants.

NATIONAL SCIENCE BOARD ANALYSIS

The committee applauds the May 2007 report by the National Science Board (2007) and the August 10, 2007, announcement by the National Science Foundation (2007c) to undertake a new, foundation-wide initiative to foster transformative research. This Transformative Research Initiative, a three-year experiment, will feature a two-tiered "early-concept" award mechanism implemented under the direction of a working group led by the Director's Office. The funding level of this new program will depend on the budget situation. The robust investments in NSF proposed by the FY 2009 budget are hopeful signs that the funding constraints and priorities of recent years may be eased. The National Academies have proposed that at least 8 percent of the budgets of federal

[1] http://nihroadmap.nih.gov/pioneer.

EXCERPTS OF THE NATIONAL SCIENCE BOARD REPORT

"Enhancing Support of Transformative Research at the National Science Foundation"

By its very nature, transformative research often is challenging and frequently crosses disciplines. It questions the status quo by proposing new (sometimes radically new) ways of approaching a fundamental scientific question. . . . Experts in the areas being challenged (many of whom may sit on review panels) may dismiss such ideas by pronouncing the research overreaching or without basis. Consequently, such ideas can remain hidden or discouraged and their breakthrough discoveries delayed or even missed.

First and foremost, these mechanisms assume that transformative research is being proposed to NSF. A recurring point made to the Board was that many paradigm-challenging ideas are simply not submitted to NSF.

Second, transformative ideas are often fragile in their early stages and often can be multidisciplinary, thus requiring extra time by a Program Officer to negotiate possible joint funding among allied programs. Given the sheer number of research proposals processed by the Foundation every year . . . there simply is insufficient time for a Program Officer to facilitate (let alone, solicit) all transformative proposals.

Third, although each NSF directorate may expend up to 5 percent of its program funds ($590 million) on such research through SGER [Small Grants for Exploratory Research] awards, only 0.5% of such funds ($29.5 million) were so expended in FY 2004.

The key is to identify individuals or teams with transformative ideas, to encourage them to submit proposals, and to nurture them through the process.

Additionally, the Board finds that NSF is viewed by much of the research community as having a reputation of funding science that has predictable productivity or opportunity for success. This reputation by the research community appears to be based both on hearsay (scientists telling other scientists that high-risk proposals are "dead upon arrival") and on actual experiences (repeated rejection of such research proposals and the low overall conventional funding rate). The Board believes that the biggest impact of such a reputation is that many researchers are unlikely to submit (or resubmit) paradigm-challenging ideas to NSF.

The Board believes that it is unreasonable to expect that small adjustments to NSF's existing programs and processes will overcome the perception among much of the external scientific community that iconoclastic ideas are not welcome at NSF. . . . NSF cannot allow the perception by any of the Nation's scientists that it does not welcome or support their ideas and aspirations. Public support of and careful investment in paradigm-challenging ideas are critical not only to continued economic growth, but also to the future welfare of our Nation.

research agencies be set aside for discretionary funding for high-risk, high-reward research to be managed by technical program managers at those agencies (NAS/NAE/IOM 2007).

The National Science Board's analysis may well apply more broadly across the federal/university research enterprise.

RECOMMENDATIONS TO GOVERNMENT

1. **Explore Grant Mechanisms and Policies to Foster Potentially Transformative Research.**

   All federal agencies should have robust programs to fund potentially transformative research that have the following characteristics and that recognize the inherent uncertainties and additional time required for such research:

It is false economy to deny program officers who manage millions of taxpayer dollars the resources necessary to engage fully with the professional communities they fund and for whom they are responsible.

- Applications should be relatively short and focused on the qualifications of the researcher, an explanation of the potentially transformative nature of the research, and an explanation of why the researcher believes the proposed approach could succeed.
- The proposal and the review process should place a premium on innovation.
- Fast-track seed money to evaluate a novel idea should be made available.
- Agencies should be open to providing longer funding periods for those proposals that require it. A possible model for sustained funding would be the system NSF uses for its research centers program—an initial six-year grant that, if moving forward appropriately, can be renewed in two additional increments for up to 11 years.

Programs should be evaluated in two phases.

(i) Effectiveness of the program mechanisms.

The first evaluation of the program should be conducted three to five years after its first awards are made and should ask the following questions: Is the program attracting potentially transformative research proposals? Do both submitted proposals and those funded under the new program differ from proposals submitted to and funded under traditional grant programs?

For instance, NIH should perform an objective evaluation of its Pioneer Award program to assess whether the award mechanisms and processes are working effectively, and whether the program is attracting transformative projects in a higher proportion than attained through the R01 grant program.

(ii) Outcomes of projects.

Evaluation of scientific outcomes of funded projects should be made no sooner than 10 years after a program's initiation. In establishing and assessing these programs, the agencies must recognize that the gestation period for transformative outcomes and the time required to understand their impact and importance can be very long. For example, hypertext was developed by DOD through the Defense Advanced Research Projects Agency (DARPANET) funding long before the World Wide Web for which hypertext has become an invaluable tool. Only a small proportion of funded research will lead to truly transformative results and new scientific paradigms, and even then the transformative impact may take some time to become apparent.

Federal research agencies are highly diverse in their missions, needs, and programs. Therefore, programs to fund potentially transformative research will and should vary across departments and agencies. Such diversity is a national asset and the foundation of the research enterprise. The entire scientific community will benefit from interagency meetings called to share information on how departments and agencies design, organize, implement, and evaluate their investments in potentially transformative research.

Transformative Discoveries Take Time: Hypertext

The invention of hypertext is usually credited to Ted Nelson (who coined the name) and Doug Englebart (who also invented the computer mouse) in the mid-1960s. Although some experimental research software was based on hypertext and hypermedia subsequently, its major impact came from its key role in Web browsers, starting in the early 1990s. The impact of the mouse began with Apple's early personal computers, well after Englebart's patent had expired. Indeed, it was only in the late 1980s that Englebart began to receive significant recognition for his prescient contributions to computing.

2. **Adopt Funding Mechanisms and Policies That Nurture Transformative Research in All Award Programs.**

   Unexpected findings trigger truly revolutionary discoveries. To advance such research, mainstream grant mechanisms also must nurture, rather than inhibit, potentially transformative research. Certainly, as stated by Perutz (1998, p. ix), "[H]ierarchical organization, inflexible, bureaucratic rules, and mounds of futile paperwork can kill [creativity]." Therefore, all federal research agencies should:

   - Charge reviewers to identify new ideas, innovation, and creativity. Consider alternative ways to select and mentor reviewers.
   - Give program administrators the flexibility and expectation to provide extra resources or time to research unexpected but promising developments. For example, NSF program officers currently have the flexibility to make supplementary Small Grant for Exploratory Research (SGER) awards. This mechanism should be used more frequently across the NSF grant programs and at other funding agencies as well.
   - Recognize in grant-reporting requirements the value of fortuitous findings not related to the main objective of the research proposal.
   - For grant renewals or new grants on the same topic, restrict the number of submitted publications and require a self-assessment of each cited publication's impact.

3. **Strengthen Application and Review Processes.**

   Peer review is the "gold standard" for competitive research award systems. NSF's (2007b) IPAMM report determined, however, that peer review now operates under considerable strain. Participation and ownership of the system by researchers seem fragile. At NIH, a loss of continuity in panel membership, rapid turnover of program officers and reviewers, an erosion of quality, and a loss of connection and engagement with the review systems they have known best now hamper the system. These problems affect all areas of research, but high-risk research proposals face even greater challenges in a stressed peer review system ill equipped to appreciate them.

   High-quality review processes attract gifted reviewers. Time wasted discourages participation. Agencies government-wide should consider the following modifications in peer and merit review systems, particularly for high-risk, high-reward proposals:

- Require recipients of multiple grants from an agency to serve as reviewers.
- Achieve greater continuity in reviewers.
- Require applicants to address the following question about their proposed research: "If this works, what long-term scientific difference will it make?" Evaluate proposals based on this criterion.
- Establish interdisciplinary review panels to consider high-risk research proposals across programs and fields.
- Evaluate renewals for first awards for high-risk, high-reward research on the basis of project execution and potential scientific impact, not on deliverables. Resist fine-grain assessments of whether a project "worked"; expect some hypotheses to fail.

High-quality review processes attract gifted reviewers. Time wasted discourages participation.

4. Invest in Program Officers.

Agency program officers are indispensable to the vitality and productivity of the research enterprise. They must have the opportunity, responsibility, and the shared expectations of their agencies and the scientific community to be leaders in their fields. The entire research system will greatly benefit if program officers are given greater opportunities to exercise leadership. The resources and administrative staff support essential to the highest caliber of scientific leadership are necessary ingredients of success. Agency resources will remain constrained, but it is false economy to deny program officers who manage millions of taxpayer dollars the resources necessary to engage fully with the professional communities they fund and for whom they are responsible.

If agencies and departments improve the professional opportunities of their research program officers, several benefits will follow. Program leadership will be strengthened, and career satisfaction will be improved. New ideas will be injected into agency and community deliberations. Researchers and program managers will be challenged in creative, timely, and innovative ways. Mutual understanding and communication will be strengthened. Counterproductive misperceptions will be identified more quickly. The return on investment of taxpayer dollars will be enhanced.

The Executive Branch and Congress should reconsider the inclination to constrain the administrative budgets of the research agencies. Instead, as research budgets are strengthened, administrative budgets should keep pace at levels that will secure the highest levels of professionalism in research program management, as has been proposed for NSF this year. To do otherwise damages the health and productivity of the enterprise itself. The following steps will strengthen the system:

- Program officers should be leaders not only within their agencies but within their external scientific communities as well.

- Program officers should be able, indeed encouraged, to attend professional meetings and to visit institutions and laboratories funded by programs for which they are responsible. Telephone and e-mail interactions are essential management and communication tools; however, they are inadequate substitutes for full professional engagement with a dynamic scientific community. At NSF, program advisory committees have routinely recommended increases in administrative budgets even in times of constrained research budgets.

- Many university faculty members serve as temporary program officers at NSF, or “rotators,” while on leave from their university. They provide essential service and leadership for NSF’s research programs. Statutory authority to use program funds for rotators is appropriate and should be retained. Consideration should be given to providing this flexibility to other agencies as well.

3 Issues Common to Early-Career and Transformative Research

The fundamental changes to funding policies and practices outlined in Sections 1 and 2 will more effectively nurture early-career scientists and encourage transformative research. A number of problems in the current system affect both funding for early-career researchers and for potentially transformative research as well as the broader funding environment. They include a peer-review system under stress and the proliferation of specialized programs that leads to inefficiencies. In addition, the incomplete tracking of demographics across all agencies, particularly of individual investigators, does not allow for a full understanding of issues critical to funding early-career researchers and potentially transformative research. In universities, the doubling of the NIH budget led universities to expand rapidly the number of research faculty and to construct new laboratory buildings without consideration of sustainability. As universities continue to expand their research capacity in light of funding constraints at the federal level, universities may increasingly find themselves planning for how salaries and research programs will be funded.

STRESS ON PEER-REVIEW SYSTEM

The peer-review system used by the federal science-funding agencies is the gold standard of decision-making and the backbone of the American research enterprise. This system of competition and merit-based selection is in large part responsible for U.S. successes and leadership in science, engineering, and technology. It is therefore of great concern that the peer-review system is currently strained.

NSF has recently documented the evidence of strain in its systems, and NIH is approaching completion of its most recent analysis of its structures and processes.

- As the applicant pool and the number of proposals per applicant increased, stress on NSF's peer-review system increased. Workloads of reviewers, program officers, and staff grew. Over the five-year period when the proposal volume increased about 50 percent, the number of reviewers increased by only 15 percent (NSF 2007b).
- More than one-third (36 percent) of reviewers report "great" or "somewhat" decreased attention to each proposal, 23 percent report diminished thoroughness of each review, and 16.5 percent report a decrease in the quality of their reviews. The report finds, however, no deterioration in the quality of proposals submitted to NSF or in awards made by the foundation. The NSF authors warn:

  > *If this trend is not reversed, it is likely to have a negative long-term impact on science and engineering, reducing both the quantity and quality of research and infrastructure. (*NSF 2007b*)*

- For NIH the application volume doubled from 1998 to 2006. To meet this demand the number of reviewers has dramatically increased, with nearly 18,000 reviewers currently involved. Even though the volume of proposals went up, the number of proposals per reviewer decreased over this time (Scarpa 2007). Thus, NIH has moved from the previous system, in which a smaller number of highly talented and experienced reviewers each evaluated enough grants that he or she could become calibrated and provide thoughtful expert advice, to the current system, which utilizes a large fraction of the academic science faculty as occasional reviewers.

The committee fully supports the efforts of NSF and NIH to strengthen their peer-review systems and commends Congress for providing additional administrative support to federal funding agencies. The preceding two sections provided specific recommendations on how the peer-review system should be modified to evaluate and nurture early-career researchers and transformative research more effectively.

RECOMMENDATIONS TO GOVERNMENT

We offer two general recommendations to government departments and agencies. Together with the specific changes proposed above, they will further strengthen the ability of the enterprise to foster the careers of young researchers and invest in potentially transformative research.

1. **Funding Agencies Should Establish New Programs Only if They Have Critical Mass.**

   Competitions for regular research grants that fund only a very low percentage of the applications do not efficiently utilize money, time, or effort. They impose adverse consequences on researchers, universities, and funding agencies alike. When competitive success rates for regular grant programs fall to single digits, review systems are stressed; program efficiency, equity, and effectiveness are compromised; misunderstanding grows; and morale of applicants and reviewers alike falls. Therefore, if necessary, agencies should reallocate funds or consolidate programs to ensure cost-effective competitions and sufficient success rates for research grant programs.

2. **Track Demographics on a Government-Wide Basis.**

   All funding agencies should track the demographics of applicants and principal investigators in a uniform manner. Aggregated data should include the submission and success rates of individual principal investigators by field within and across agencies. The intent is to answer questions such as "What percentage of researchers who receive a first award never submit another proposal? How many successful NSF awardees also receive awards from NIH, DOD, DOE, NASA, or other agencies?" Databases of scientists should include those working in the federally funded laboratories such as NIST, the DOE Office of Science, and the NIH intramural program. The difficulties encountered by early-career researchers will be addressed effectively only if all agencies work in cooperation to gain a more complete understanding of their investigator populations by field and career path.

The difficulties encountered by early-career researchers will be addressed effectively only if all agencies work in cooperation to gain a more complete understanding of their investigator populations by field and career path.

RECOMMENDATIONS TO UNIVERSITIES

We offer two additional recommendations to our universities. Each presents serious challenges, and neither is easily accomplished. Furthermore, such recommendations carry the risk of oversimplifying a complex and historically well-entrenched set of circumstances, which differ substantially among fields and institutions. However, the future health of the enterprise as a whole now requires fresh reconsideration of both proposals.

1. **Universities Should Accept Greater Institutional Responsibility for the Salaries of Faculty Members.**

   The federal government recognizes that faculty salary support is a legitimate direct cost of research. Thus, faculty account for their time spent on research, and a portion of that time (which could be up to 100 percent) can then be charged to research grants. Universities typically expect or require research faculty to provide at least their summer salaries and medical school faculty members to provide half or even all of their salaries from research funds. Institutions—especially medical schools—have tended to enlarge their faculty in times of expanding federal investment by shifting the salary burden to faculty. For the federal funding agencies, this salary support lessens the number of projects that can be funded. For the faculty member, this requirement fosters conservative, risk-averse thinking as the path to sustained funding. When funding tightens, faculty, especially early-career faculty, are too often left in untenable positions.

> Universities need to develop mechanisms to pay a greater portion of faculty salaries. This will free funds within research agency budgets that can then be reallocated to support research.

   Universities need to develop mechanisms to pay a greater portion of faculty salaries. This will free funds within research agency budgets, which can then be reallocated to support research.

   This suggestion seriously challenges institutional planning for programs and research facilities. Nevertheless, a comprehensive reexamination of this issue and a fundamental change in approach are needed.

2. **In Building New Facilities and Programs, Universities Should Shoulder a Larger Share of the Financial Cost.**

   As universities raise funds to build research buildings, campaign goals should include continuing responsibility to maintain each building and to support new programmatic activities, including the initial stages of transformative research. University resources are also needed to buffer their scientific enterprise from the ups and downs of federal funding. If funding campaigns for construction were expected to assume some portion of the research expenses, it would lead universities to limit excessive building programs based on unrealistic expectations about the expansion of the research enterprise. Many universities are now beginning to recognize the wisdom of setting aside money from building campaigns for research and equipment. Universities could go even further and underwrite the creation and maintenance of centers specifically devoted to potentially transformative research.

Conclusion

America will meet the challenges posed to its global leadership in research and education, ensuring the continuing prosperity of the nation, only by investing vigorously in early-career researchers and in potentially transformative research.

Early-career researchers face greater difficulties than ever in launching what should be one of the most productive stages of their careers. Too much time is being spent preparing and resubmitting grant applications. Productivity is being compromised and morale is suffering. These realities are being communicated to students and are affecting their career decisions. The nation faces a thinning of the talent pool on which our future prosperity, health, and security depend.

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The constant hunt for dollars is fostering conservative thinking in laboratories and agencies that is impeding the impact of research. As junior and senior faculty compete in an intense grant-writing mill, the thought, "Don't put it in your grant proposal unless you know it will work," too often guides them.

In a time of unprecedented fiscal constraint, this report urges a broad discussion of these issues, and collaborative action to address them by all stakeholders: government, industry, universities, and foundations.

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Committee Biographies

David Baltimore is the Robert Andrews Millikan Professor of Biology and President Emeritus of the California Institute of Technology, and Chairman of the Board of the American Association for the Advancement of Science. He shared the 1975 Nobel Prize in Medicine for the discovery of reverse transcriptase. Since then he has published on the genetics of cancer, the workings of the HIV virus and AIDS vaccine candidates, and fundamental observations in molecular immunology. He was founding director of the Whitehead Institute for Biomedical Research and President of Rockefeller University. Today he heads the Baltimore Lab at Caltech to look for ways to boost the immune system genetically against infectious pathogens, particularly HIV. A recipient of the National Medal of Science, he was elected a Fellow of the American Academy of Arts and Sciences in 1974.

Thomas R. Cech (Chair, *ARISE* report) is President of the Howard Hughes Medical Institute, a recipient of the Nobel Prize in Chemistry, and an awardee of the National Medal of Science. His current research focuses on ribozyme structure and on telomerase. In 1978 he joined the faculty of the University of Colorado, Boulder, where he became a Howard Hughes Medical Institute Investigator in 1988 and Distinguished Professor of Chemistry and Biochemistry in 1990. He chaired the National Academies Committee on Bridges to Independence. Elected to the National Academy of Sciences and also awarded a lifetime professorship by the American Cancer Society, he was elected a Fellow of the American Academy of Arts and Sciences in 1988.

Steven Chu is Director of the Lawrence Berkeley National Laboratory and Professor of Physics and Molecular and Cell Biology at the University of California, Berkeley. Previously he was at Stanford and Bell Laboratories. His research includes tests of fundamental physics, laser cooling and trapping (for which he shared the 1997 Nobel Prize in Physics), polymer physics, and single-molecule biology. He cochaired the 2007 InterAcademy Council study "Lighting the Way: Toward a Sustainable Energy Future" and was on the Advisory Committees to the Directors of the National Institutes of Health and the National Nuclear Security Agency. He serves on the boards of the Hewlett Foundation, the

University of Rochester, and the NVIDIA Corporation, and is a member of numerous American, Chinese, and Korean academies. He has nine honorary degrees and was elected a Fellow of the American Academy of Arts and Sciences in 1992.

France A. Córdova became President of Purdue University in 2007. Previously she was Chancellor of the University of California, Riverside, where she was also Distinguished Professor of Physics and Astronomy. Earlier she was Professor of Physics and Vice Chancellor for Research at University of California, Santa Barbara, and Chief Scientist at NASA. Her work has been in the areas of observational and experimental astrophysics, multispectral research on x-ray and gamma-ray sources, and space-borne instrumentation. Author of more than 150 scientific papers, she has a current experiment flying on the European Space Agency's X-Ray Multi-Mirror Mission. Honored with the NASA Distinguished Service Medal and recognized as a 2000 Kilby Laureate, she is a Fellow of the American Association for the Advancement of Science and the Association for Women in Science. She was elected a Fellow of the American Academy of Arts and Sciences in 2008.

Thomas E. Everhart is President Emeritus of the California Institute of Technology. He was earlier Chancellor at the University of Illinois at Urbana-Champaign, Dean of the College of Engineering at Cornell University, and a faculty member at the University of California, Berkeley. His research has focused on the generation and application of very-small-diameter electron beams, first to scanning electron microscopy and later to microfabrication. He has been a member of numerous academic and corporate boards, including the Council on Competitiveness. A member of the National Academy of Engineering, the Böhmische Physikalische Gesellschaft, and the Royal Academy of Engineering, he is also a Fellow of the American Association for the Advancement of Science and the Institute of Electrical and Electronics Engineers. He was elected a Fellow of the American Academy of Arts and Sciences in 1990.

Richard B. Freeman holds the Herbert Ascherman Chair in Economics at Harvard University and serves as Faculty Director of the Labor and Worklife Program at the Harvard Law School. He is also Director of the Labor Studies Program at the National Bureau of Economic Research and Senior Research Fellow in Labour Markets at the London School of Economics Centre for Economic Performance. His published research includes studies of the job market for scientists and engineers; the growth and decline of unions; the effects of immigration and trade on inequality; restructuring European welfare states; income distribution and equity in the marketplace; and the job market in China. He is currently serving on the National Academies Committee on Capitalizing on the Diversity of the Science and Engineering Workforce in Industry. A Fellow of Sigma Xi, he was elected a Fellow of the American Academy of Arts and Sciences in 1996.

David Goldston is a Visiting Lecturer at the Harvard University Center for the Environment and writes a monthly column on science policy, "Party of One," for the journal *Nature*. From 2001 through 2006 he was the Chief of Staff of the U.S. House Committee on Science. In all, he served more than 20 years on Capitol Hill as a press secretary, committee staffer, and legislative director, specializing in environmental and science and technology policy. In 1994 he worked for the Council on Competitiveness as the project director for the science policy report, "Endless Frontier, Limited Resources." In 2007 he was a Visiting Lecturer at Princeton University's Woodrow Wilson School of Public and International Affairs. He has a B.A. in history from Cornell University and completed the coursework for a Ph.D. in American history at the University of Pennsylvania.

Susan L. Graham is the Pehong Chen Distinguished Professor of Electrical Engineering and Computer Science Emerita at the University of California, Berkeley. Her research addresses programming language implementation, software tools, software development environments, and high-performance computing. She has done seminal research in compiler code generation and optimization. Her recent projects include the Titanium system for language and compiler support of explicitly parallel programs and the Harmonia framework for high-level interactive software development. She was a member of the Harvard Board of Overseers from 2001 to 2007, serving as President in 2006–2007. A member of the National Academy of Engineering and a Fellow of the Association for Computing Machinery and the American Association for the Advancement of Science, she was elected a Fellow of the American Academy of Arts and Sciences in 1995.

H. Robert Horvitz is the David H. Koch Professor of Biology at the Massachusetts Institute of Technology, where he joined the faculty in 1978. He is also a Member of the MIT McGovern Institute for Brain Research and the MIT Center for Cancer Research and an Investigator at the Howard Hughes Medical Institute. He discovered key genes that control cell death in *C. elegans*. Nearly identical genes have been identified in other animals, including humans. For this work and for his studies concerning organ development in *C. elegans*, Horvitz shared the 2002 Nobel Prize in Physiology or Medicine. President of the Genetics Society of America in 1995, he is also a member of the National Academy of Sciences, the Institute of Medicine, the American Academy of Microbiology, the American Philosophical Society, and the Physiological Society (London). He was elected a Fellow of the American Academy of Arts and Sciences in 1994.

Linda Katehi is the Provost and Vice Chancellor for Academic Affairs and Professor of Electrical and Computer Engineering at the University of Illinois at Urbana-Champaign. Earlier she was the John A. Edwardson Dean of Engineering at Purdue University and Associate Dean for Academic Affairs and Graduate Education in the College of Engineering at the University of Michigan. She has pioneered the development of on-wafer integration techniques that have led to low-cost, high-performance integrated circuits for radar, satellite, and wireless applications. A member of the National Academy of Engineering, a Fellow and Board member of the American Association for the Advancement of Science, Chair of the National Academy of Engineering Committee on K-12 Engineering Education, a member of the National Academy of Sciences Committee on the Integrity of Research Data, and a board member of the EU Cyprus Institute, she is also a Fellow of Institute of Electrical and Electronics Engineering and a member of Sigma Xi.

Peter S. Kim is President of Merck Research Laboratories (MRL), responsible for Merck's drug and vaccine discovery and development activities. Before joining MRL in 2001, he was Professor of Biology and Associate Head of the Department of Biology at the Massachusetts Institute of Technology, an Investigator at the Howard Hughes Medical Institute, and a member of the Whitehead Institute for Biomedical Research. His research discovered how proteins cause membranes to fuse—a central feature of all life—designed compounds that stop membrane fusion by the AIDS virus, and pioneered novel HIV vaccine efforts that target transient membrane-fusion intermediates. He is a member of the Board of Directors of Fox Chase Cancer Center and the Whitehead Institute of Biomedical Research. He is a member of the National Academy of Sciences and the Institute of Medicine (IOM), and serves as a member of the IOM Council. He was elected a Fellow of the American Academy of Arts and Sciences in 2008.

Neal Lane is the Malcolm Gillis University Professor at Rice University, where he is a Senior Fellow at the James A. Baker III Institute for Public Policy and Professor in the Department of Physics and Astronomy. He served as Assistant to the President for Science and Technology and Director of the White House Office of Science and Technology Policy from 1998 to 2001, and as Director of the National Science Foundation from 1993 to 1998. He was elected a Fellow of the American Academy of Arts and Sciences in 1995 and is a member of the Academy Council. He cochairs the Academy's Initiative for Science, Engineering, and Technology. He is an active participant in, and author for, the Academy's Reconsidering the Rules of Space project.

C. D. (Dan) Mote, Jr. is President of the University of Maryland and Glenn L. Martin Institute Professor of Engineering. Earlier he was Vice Chancellor at the University of California, Berkeley, and held the FANUC Chair in Mechanical Systems. He has held numerous positions on government committees, including Vice Chair of the Review Committee for Department of Defense Basic Research and Co-Chair of The Government-University-Industry Research Roundtable. His research has focused on the dynamics of gyroscopic systems and biomechanics. He is a member of the National Academy of Engineering, is a recipient of its Founders Award, and serves on its Council. An Honorary Member of the

American Society of Mechanical Engineers International, he is a Fellow of the International Academy of Wood Science, the Acoustical Society of America, and the American Association for the Advancement of Science. He was elected a Fellow of the American Academy of Arts and Sciences in 2004.

Daphne Preuss is Chief Executive Officer and Co-Founder of Chromatin, Inc., and on leave of absence from the University of Chicago, where she is the Albert D. Lasker Professor of Molecular Genetics and Cell Biology. Her research focuses on engineering plant chromosomes that contain the genes needed for improving crop nutrition or energy production. It also explores plant pollination and the pollen surface molecules that trigger allergic responses. A past Investigator at the Howard Hughes Medical Institute, she has served on the Board of Governors at Argonne National Laboratory since 2003. A David and Lucile Packard Fellow, she is also a Searle Scholar and a Lifetime National Associate of the National Academy of Sciences.

David D. Sabatini is the Frederick L. Ehrman Professor and Chairman of the Cell Biology Department at New York University School of Medicine. As a pioneer molecular cell biologist, highly skilled in both morphological and biochemical approaches, Sabatini was a key figure in laying the foundation for the field of intracellular protein trafficking with his seminal studies on co-translational translocation of nascent polypeptides in the endoplasmic reticulum and the intracellular sorting of plasma membrane proteins in polarized epithelial cells. Sabatini is a member of the National Academy of Sciences and a foreign associate of the French Academy of Sciences, which awarded him the Grand Medaille d'Or in 2003. He was elected a Fellow of the American Academy of Arts and Sciences in 2000 and is a member of the Academy's Council and Trust.

Randy Schekman is Professor of Molecular and Cell Biology at the University of California, Berkeley, and an Investigator at the Howard Hughes Medical Institute. In 2002, he received the Lasker Award, the nation's highest award for basic medical research, for cell secretion research important to the biotech industry. His research mapped out one of the body's critical networks: the system in all cells that shuttles hormones and enzymes out and adds to the cell surface so it can grow and divide. A member of the National Academy of Sciences and recipient of the Gairdner International Award in 1996, Schekman was elected president of the American Society for Cell Biology in 1999 and selected as Editor-in-Chief of the *Proceedings of the National Academy of Sciences* in 2006. He was elected a Fellow of the American Academy of Arts and Sciences in 2000 and serves on its Council.

Richard Scheller is Executive Vice President for Research at Genentech. Previously he was Professor of Molecular and Cellular Physiology and Biological Sciences at Stanford University, where he joined the faculty in 1982. In 1994 he became an Investigator with the Howard Hughes

Medical Institute. His work has earned him numerous awards, including the 1997 National Academy of Sciences Award in Molecular Biology. Author of more than 200 papers in peer-reviewed scientific journals, he is a member of the National Academy of Sciences, and has served on numerous advisory boards, including the National Advisory Mental Health Council of the National Institutes of Health. He was elected a Fellow of the American Academy of Arts and Sciences in 1998.

Albert H. Teich is Director of Science and Policy Programs at the American Association for the Advancement of Science (AAAS), where he is responsible for the Association's activities in science and technology policy and serves as a key spokesman on science policy issues. Prior to joining the AAAS staff in 1980 he taught science and technology policy at George Washington University. He is the author of numerous articles and editor of several books, including *Technology and the Future*, a widely used textbook on technology and society, the eleventh edition of which will be published in 2008. Teich is a Fellow of AAAS and the recipient of the 2004 Award for Achievement in Science Policy from the Washington Academy of Sciences.

Mark S. Wrighton is Chancellor of Washington University in St. Louis. Previously he was at the Massachusetts Institute of Technology (MIT), where he joined the faculty in 1972. He was Head of the Department of Chemistry from 1987 until 1990, when he became Provost of MIT. His research focuses on transition metal catalysis, photochemistry, surface chemistry, molecular electronics, and photoprocesses at electrodes. A past Chair of the Association of American Universities, he currently serves on numerous academic, community, and corporate boards and is Vice Chair of the National Academy of Sciences Committee on America's Energy Future. A former MacArthur Fellow, he is also a Fellow of the American Association for the Advancement of Science and a member of the American Philosophical Society. He was elected to the American Academy of Arts and Sciences in 1988.

Keith Yamamoto is Executive Vice Dean of the School of Medicine at the University of California, San Francisco (UCSF), and Professor of Cellular and Molecular Pharmacology. A member of the UCSF faculty since 1976, he has served in numerous capacities, including Chair of the Department of Cellular and Molecular Pharmacology. His research focuses on the mechanisms of signaling and gene regulation by intracellular receptors, which mediate the actions of several classes of essential hormones and cellular signals. A founding editor of *Molecular Biology of the Cell*, he serves on numerous editorial boards, scientific advisory boards, and national committees. A member of the National Academy of Sciences and the Institute of Medicine, and a Fellow of the American Association for the Advancement of Science, he was elected a Fellow of the American Academy of Arts and Sciences in 1989.

Huda Y. Zoghbi is a Professor in the Departments of Molecular and Human Genetics, Pediatrics, Neurology, and Neuroscience at the Baylor College of Medicine, where she joined the faculty in 1988. She is also an Investigator at the Howard Hughes Medical Institute. Her research focuses on genetic and cell biological approaches to explore the pathogenesis of polyglutamine neurodegenerative diseases and Rett syndrome and to study genes essential for normal neurodevelopment. A member of several professional organizations, she serves on the editorial boards of several prominent journals. In 2000 she was elected to the Institute of Medicine, and in 2004 she was elected to the National Academy of Sciences.

Leslie C. Berlowitz (*ex officio*) is Chief Executive Officer and the William T. Golden Chair at the American Academy of Arts and Sciences. She is former Vice President for Academic Advancement and former Deputy Vice President for Academic Affairs at New York University. She has served as an advisor to the National Endowment for the Humanities, the Corporation of Yaddo, the National Humanities Alliance, and the Robert Wood Johnson Foundation. Her publications include *America in Theory* (Oxford University Press, 1988), with Denis Donoghue and Louis Menand; *Greenwich Village: Culture and Counterculture* (Rutgers University Press, 1993), with Rick Beard; and *Restoring Trust in American Business* (MIT Press, 2005), with Jay W. Lorsch and Andy Zelleke. She was elected a Fellow of the American Academy of Arts and Sciences in 2004.

John C. Crowley is a consultant to the American Academy of Arts and Sciences. He has also been a consultant to the Stevens Institute of Technology and to the Council on Competitiveness since his retirement in 2005 as Director of the Massachusetts Institute of Technology Washington Office, which he joined at its creation in 1991. He was named Vice President for Federal Relations at MIT in 2000. Prior to his work at MIT, he served for 19 years as the first Vice President of the Association of American Universities. Recently honored with the MIT Excellence Award, he is a Fellow of the American Association for the Advancement of Science.

Katie Donnelly is Program Officer for Science, Technology, and Global Security at the American Academy of Arts and Sciences. Prior to joining the staff she worked for Representative Edward J. Markey as a Legislative Assistant on matters related to nuclear nonproliferation, energy, defense, security, science research and development, and human rights. She received her Ph.D. in earth and environmental science from Columbia University, where she lectured. She was a Congressional Science and Technology Fellow with the American Association for the Advancement of Science.

“Among the greatest risks America can take in its science and engineering research enterprise is to become risk averse or to overlook the immense contributions that have historically been made in these fields by younger researchers. The American Academy’s ARISE report points the way to address the opportunities implicit in these considerations.”

—Norman R. Augustine, Retired Chairman and Chief Executive Officer, Lockheed Martin Corporation

“Faculty in science and engineering are the idea engines that drive technological progress in America. The American Academy’s ARISE report provides a frank assessment of the danger we face if, due to increasingly constrained funding, we lose our most promising scientists from the basic science arena.”

—Bonnie L. Bassler, Squibb Professor and Director of Graduate Studies in the Department of Molecular Biology, Princeton University; Howard Hughes Medical Institute Investigator

“It is in our own direct interest to pursue this study’s recommendations for nurturing a vibrant science pipeline. Professional excellence, technology, and innovation are the lifeblood of our competitive success as an economic system.”

—Martin L. Leibowitz, Managing Director, Morgan Stanley; Chairman of the Board, Institute for Advanced Study

“Tom Cech and his colleagues address two of the most significant problems in today’s research environment: the delays in establishing the independence of new investigators and the reluctance to support research that can fundamentally change the way we think. The recommendations will be of interest to those in government, other funding agencies, and universities who have the potential to change current practices.”

—Harold Varmus, President, Memorial Sloan-Kettering Cancer Center

“Focused, sensible, realistic, well-researched, and well-documented, this report addresses two primary weaknesses in federal research strategy. Our national ability to innovate and compete ultimately depends on attracting the best and brightest young men and women to research careers and enabling them to pursue bold new ideas. Hence, the guidance in this report is critically important.”

—Charles M. Vest, President, National Academy of Engineering