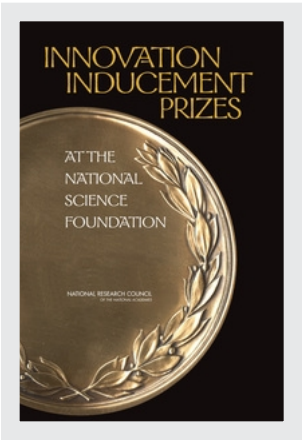

Innovation Inducement Prizes at the National Science Foundation

DETAILS

72 pages | 6 x 9 | PAPERBACK

ISBN 978-0-309-10465-4 | DOI 10.17226/11816

AUTHORS

Committee on the Design of an NSF Innovation Prize, National Research Council

INNOVATION INDUCEMENT PRIZES

AT THE NATIONAL SCIENCE FOUNDATION

Committee on the Design of an NSF Innovation Prize
Board on Science, Technology, and Economic Policy
Policy and Global Affairs

NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

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

THE NATIONAL ACADEMIES 500 FIFTH STREET, N.W. Washington, D.C. 20001

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This study was supported by Contract No. OIA-0629535 between the National Academies and the National Science Foundation. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of the agency that provided support for the project.

International Standard Book Number-13: 978-0-309-10465-4
International Standard Book Number-10: 0-309-10465-3

A PDF version is available at *http://www.nap.edu*

Limited copies are available from:

Board on Science, Technology, and Economic Policy
National Research Council
500 Fifth Street, N.W., Keck Center 574, Washington, D.C. 20001
Phone: (202) 334-2200
Fax: (202) 334-1505
E-mail: *step@nas.edu*

Printed in the United States of America

THE NATIONAL ACADEMIES

Advisers to the Nation on Science, Engineering, and Medicine

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

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

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

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

www.national-academies.org

COMMITTEE ON THE DESIGN ON AN NSF INNOVATION PRIZE

MARK B. MYERS, Chair, Senior Vice President, Science and Technology, Xerox Corporation (retired)
ERICH BLOCH, Principal, The Washington Advisory Group
STUART I. FELDMAN, Vice President, IBM
MERTON C. FLEMINGS, Professor of Materials Science and Engineering, Director, Lemelson-MIT Program, Massachusetts Institute of Technology
CLAIRE GMACHL, Assistant Professor of Electrical Engineering and Director, Mid-InfraRed Technologies for Health Care (MIRTHE), Princeton University
THOMAS A. KALIL, Special Assistant to the Chancellor for Science and Technology University of California, Berkeley
DAVIS MASTEN, Prinicpal, Cheskin Associates Inc.
KAREN E. NELSON, Investigator, The Institute for Genomic Research (TIGR)
RICHARD G. NEWELL, Senior Fellow, Resources for the Future
PETER M. RENTZEPIS, Presidential Chair and Professor of Chemistry, School of Physical Sciences, University of California, Irvine
SUZANNE SCOTCHMER, Professor of Economics and Public Policy, University of California, Berkeley
MARGARET STEINBUGLER, Manager, Transportation Fuel Cell Product Development, UTC Fuel Cells

Staff

STEPHEN A. MERRILL, Study Director
CHRISTOPHER T. HILL, Consultant, George Mason University
PROCTOR REID, Director, Program Office, National Academy of Engineering
BENJAMIN ROBERTS, Christine Mirzayan Science and Technology Policy Graduate Fellow, Summer 2006
MAHENDRA SHUNMOOGAM, Senior Program Assistant

Preface and Acknowledgments

The FY 2006 Science, State, Justice, Commerce, and Related Agencies Appropriations Act (Public Law 109-108) directed the National Science Foundation (NSF) to use available funds for "innovation inducement prizes." Following guidance in the accompanying House Report 109-118, the agency in June 2006 arranged with the National Academies' Science, Technology, and Economic Policy (STEP) Board to conduct a fast-track study with the following objectives:

> [P]ropose a plan for administering prizes to individuals or teams that achieve novel solutions to specified social or research needs or capitalize on recognized research opportunities. Evaluate the goals that could be served by such a competition. Propose areas of basic or applied research that would be suitable for a prize competition. Address other issues of design including financial award, rules framework, administration, and unintended consequences that could facilitate or hinder achieving the goals.

To address this task the National Academies assembled a committee composed of experts in private sector technology management, publicly sponsored research, public policy and administration, marketing, and economics. The two economists on the panel have had a long-standing interest in the strengths and limitations of the prize mechanism and contributed to the academic literature on the subject. The committee included experts in several scientific and engineering disciplines, including molecular biology, materials, computer science and electrical engineering, and optics. Most of these investigators are or have been beneficiaries of

NSF research support at one time or another. A former director of the NSF and a former White House National Economic Council official also served on the panel. Both played key roles in a 1999 National Academy of Engineering (NAE) workshop that led to an important endorsement of prizes as an innovation policy tool, the former as chair of the steering committee, the latter in commissioning the activity. The committee was fortunate to have the advice and drafting assistance of Christopher T. Hill, George Mason University professor of technology and public policy, and Proctor Reid, director of the NAE Program Office. We are grateful to all of these contributors to this report.

In the three and one-half months between its appointment and the submission of its report to external review the committee held two two-day meetings, one incorporating a public session with presentations by the following: Arden L. Bement Jr., director, NSF; Ken Davidian, director, NASA Centennial Challenges; Ben Shelef, Spaceward Foundation; and Peter Diamandis, president, X-Prize Foundation.

Project staff interviewed key staff members of the relevant appropriations and authorization committees and a number of other people with practical experience with prizes and familiarity with NSF's missions, traditions, and culture. The academic literature on prizes was, of course, thoroughly reviewed. Nevertheless, because of the limited empirical base for conclusions about what circumstances are best suited for the use of prize contests to promote innovation, the committee had to rely on collective judgments for many of its conclusions and recommendations.

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Academies Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the process.

We wish to thank the following individuals for their review of this report: MRC Greenwood, University of California, Santa Cruz; Rebecca Henderson, Massachusetts Institute of Technology; Frank Huband, American Society for Engineering Education; Dean Kamen, DEKA Research & Development Corporation; Paul Kaminski, Technovation Inc.; Ron Kurjanowicz, DARPA; and Patrick Windham, Independent Consultant.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

Mark B. Myers, Chair
Stephen A. Merrill, Study Director

Contents

Summary

As one of their measures to promote innovation, governments and private parties have periodically awarded prizes not only for recognizing original technical achievements but also for solutions to predefined scientific or technological problems or demonstrations of the feasibility of specified unprecedented accomplishments. The latter, known as inducement prizes, have played a role in advancing commercial aviation and maritime navigation, solving mathematical problems, and in a few other arenas. Inducement prize contests are clearly not well suited to all research and innovation objectives. But through the staging of competitions they are thought to have in many circumstances the virtue of focusing multiple group and individual efforts and resources on a scientifically or socially worthwhile goal without specifying how the goal is to be accomplished and by paying a fixed purse only to the contestant with the best or first solution. Inducement prize contests with low administrative barriers to entry can attract a diverse range of talent and stimulate interest in the enterprise well beyond the participant pool. The limited historical experience and theoretical literature suggest that the success of prizes in these respects depends on the choice of targets and design features as well as the administrative competence of the sponsor.

A 1999 National Academy of Engineering (NAE) workshop and report renewed interest in the use of inducement prizes after a period of relative neglect. Since then the Defense Advanced Research Projects Agency (DARPA) and National Aeronautics and Space Administration (NASA) have instituted prize contests to further their missions. A private

U.S. foundation has been established to award prizes for private travel to space, automotive fuel economy, genetic sequencing, and other objectives. Legislation is pending in Congress to authorize the Department of Energy (DOE) to award prizes for advances in hydrogen fuel development. And the FY 2006 Science, State, Justice, Commerce and Related Agencies Appropriations Act (Public Law 109-108) directed the National Science Foundation (NSF) to use available funds to establish an inducement prize program and to engage the National Academy of Sciences in its design.

The committee believes that an ambitious program of innovation inducement prize contests will be a sound investment in strengthening the infrastructure for U.S. innovation. Experimental in its early stages, the program should be carried out in close association with the academic community, scientific and technical societies, industry organizations, venture capitalists, and others. The legislative mandate nevertheless poses a substantial challenge to NSF. The agency sees itself and is seen as working primarily through the competitive award of grants to academic scientists and engineers for self-initiated proposals about how to advance basic knowledge of natural and social phenomena. It has limited experience in supporting innovations intended to solve societal problems and no experience in administering innovation prize contests. Provided, as Congress stipulated, that the objective of promoting innovation is interpreted broadly to focus on high risk/high payoff research projects with ambitious scientific and technological objectives rather than narrowly on commercial or near-commercial innovations, the committee recommends that NSF embrace this challenge as an opportunity both to advance science and engineering and to learn a great deal more than we now know about what may prove to be a valuable mode of support for research and innovation.

AN EXPERIMENTAL PRIZE PROGRAM

The committee recommends that the agency take an experimental approach to implementing its congressional directive to award such prizes, especially during the program's formative period. By an experimental program we do not mean that prizewinning would necessarily entail use of experimental methods nor that the program would be set up as a rigorous scientific experiment with appropriate controls. Instead, the program should be conducted with careful attention to evaluation, measurement, and use of feedback about the program itself. There is much to learn about how to determine the appropriate goals for inducement prizes, set the terms and conditions under which prize contestants participate and winners are recognized, establish an appropriate time frame for award of a prize, and decide whether and how to partner with or

outsource prize administration to nongovernmental entities, among many other issues. NSF certainly has the capacity to make good use of this learning opportunity.

In the program's initial phase NSF should offer several small-scale prizes ($200,000 to $2 million each) in diverse areas that differ regarding prize scope and scale, contest duration, engagement of outside groups, and other features. The committee believes that NSF could award three or four such prizes in the first two years of the program and one or two each year thereafter. The annual cost of this component of the program, excluding administrative expenses, would be in the range of $800,000 to $8 million initially and perhaps $400,000 to $4 million each year thereafter. **Simultaneously, NSF should commence planning for much larger awards ($3 million to as much as $30 million) to encourage more complex innovations, well beyond the state of the art and addressing significant economic, social, or other challenges to the United States.** NSF could conduct a major prize contest every few years. Designing such a contest may require one to three years of preliminary planning and consultation and the competition itself could extend over 5 to as many as 10 years. The award budget for this component of the NSF program could range from $5 million to $50 million annually at steady state, depending on the number of contests. For branding or public recognition purposes it may be desirable to use different titles for the two sets of prizes.

ADMINISTERING A PRIZE PROGRAM

NSF should assume primary responsibility for developing, communicating, implementing, and evaluating this program through a dedicated program staff, perhaps designated as the Office of Innovation Prizes (OIP), with its own appointed advisory committee. NSF should seek "no-year" congressional appropriations, in addition to its request for current year appropriations for its research and education mission, to pay for the prize awards. No-year budget authority would help ensure that funds for large prize awards accumulate and remain available until multiyear contests are completed. While initiating the first series of prizes, NSF should seek legislative authorization for the program, allowing the agency considerable latitude in administering it. Such authorization could require periodic reporting on the program's status and progress to Congress and the general public.

There are many ways that NSF could make full use of the interests and capabilities of other federal agencies and either nonprofit or for-profit private sector entities. **In some cases it may be desirable for NSF to partner with another agency to award a prize related to that agency's portfolio (e.g., energy supply, environmental protection, public health,**

supercomputing). NSF should consult widely with professional, technical, and amateur societies, industry associations, entrepreneurs, early-stage investors, industry research organizations, and others in identifying appropriate prize topics and reaching out to potential participants beyond NSF's traditional academic constituency. Communicating in advance with the potential range of applicants can help determine how to motivate participation. On a case-by-case basis there may be important benefits to NSF in contracting with one or more external organizations to assist in the design and conduct of a prize contest. These assets could include deep knowledge of a technical domain and its community of researchers, ability to raise funds to supplement prize awards, and expertise in marketing and branding.

To maximize the learning opportunity represented by the prize program, NSF should engage one or more external evaluation teams to track the program's development and near-term impacts from its earliest stages. In the early years it would be clearly premature to attempt to determine whether NSF had accomplished the prize program goal of producing significant innovations for the nation. Instead, a formative evaluation strategy would focus on

- whether the program is attracting large numbers of contestants more diverse than NSF's largely academic constituency,
- whether private funds are forthcoming to support contestants and from what sources and for what reasons,
- what spin-off activities result from contests,
- whether public awareness of innovation or the goal of a particular prize is enhanced,
- and whether NSF's public image is affected by its sponsorship of prize contests.

In addition to these short-term impacts, early evaluation should also focus on determining what features of the contests seem to contribute to their success or lack of success. NSF should consider conducting a post-prize marketing review to determine what proportion of potential participants was reached and what communications techniques were most effective.

GENERAL FORMS AND RULES OF NSF PRIZE CONTESTS

For each prize contest NSF and ultimately its director should decide the topic and type of contest, the rules of participation and competition, and the winner.

The committee distinguishes between forms and rules that would

apply generally to all prize contests sponsored by NSF and rules specific to each contest. In the former category the committee offers the following guidance:

- **Contests should be designed around objectively measurable outcomes to give clear guidance to contestants and minimize the role of subjective judgments and controversy about outcomes.**
- **Of the two principal types of innovation inducement prize contests ("first-past-the-post," in which the award is to the first team or individual who accomplishes a stated contest objective, and "best-in-class," in which the winner is the team or individual who comes closest to achieving the contest objective within a specified time) the committee prefers first-past-the-post contests with set time limits for both smaller and larger prizes, although we encourage experimentation with both types and with combinations.** For example, in a first-past-the-post contest with an especially challenging objective requiring considerable time to accomplish, the award of intermediate best-in-class prizes may spur progress toward the final objective and help sustain public interest.
- **NSF should require registration although not usually prequalification or payment of fees by contestants.** To encourage participation the window for registration should be open for some period of time after a prize contest is announced. Registration should identify the sponsoring institution or corporation, if any, the leader and principal members of the team, and their affiliations. The participants should at a minimum acknowledge understanding of and agreement to abide by contest rules, including acceptance of NSF decisions regarding winners. No additional financial accounting and recordkeeping should be required where there is no use of public funds to compete for a prize.
- As the premier public sponsor of research in many fields, **NSF should not bar its own former or current grantees from competing nor attempt to prohibit the use of related grant funds.** Indeed, there may be cases where it is appropriate for NSF to combine a grant competition with a prize competition.
- **Contestants should not be required to indemnify NSF for any legal liabilities arising from the research, testing, or commercialization of an innovation developed in pursuit of a prize.**
- Because one of the purposes of an NSF innovation prize program is to strengthen U.S. innovative capacity, **it is appropriate to restrict participation to U.S.-incorporated or chartered entities and teams led by U.S. citizens or permanent residents.** This rule would allow participation by U.S.-registered subsidiaries of foreign-based companies and by temporary immigrants on study or work visas as team members.

- **Federal employees should not be eligible to lead or participate directly in teams competing for an NSF prize, nor should entrants be sponsored by organizations such as Federally Funded Research and Development Centers (FFRDCs) or Government-Owned, Contractor-Operated (GOCO) laboratories.** Federal facilities may be used and federal employees consulted by nonfederal participants if these services are available to all contestants on an equitable basis.
- **NSF should be able to terminate a contest before its announced end date if the objective has been achieved by an entity that did not or, in the case of a foreign entity, could not register to participate.**
- **The determination of winners should be made by the NSF director,** whose decision on technical grounds should be final. The director should develop a mechanism for appeals of results on procedural grounds. This should be a rare occurrence.
- **The government should not own, control, or influence the disposition of intellectual property developed by contestants in the course of competing for a prize, with the exception that a winner who declines to put the winning innovation into commercial practice or to license it within a reasonable time may be required to enter into good faith negotiations with a willing licensee.** If the winning innovation were developed in any part using federal funds, the Bayh-Dole Act would apply. Any participant under consideration for the award of a prize should be required to make a good faith effort to identify other parties' intellectual property used in the winning innovation and to acknowledge the need for licenses from those owners in order to put it into commercial practice.

CHOOSING TARGETS AND CONTEST-SPECIFIC RULES

Without question NSF's most challenging task is selecting appropriate prize topics and crafting prize-specific rules governing the type of contest, size of award, criteria for winning, and method by which winning is determined. The committee considered a number of candidates—nanotechnology self-assembly, chemical sensors for pollutants, "green" substitutes for harmful chemical solvents and reagents, catalysts for converting cellulosic biomass into liquid fuels, advances in computing architecture and performance, low carbon energy systems, and learning technology for teaching science and mathematics—not with an eye toward recommending them to NSF but as a basis for understanding the requirements of this task. We concluded that each of these fields has potential to yield one or more worthy prize contests, but determining the right objective and terms of competition is a difficult job likely to differ somewhat for each contest.

The actual selection of topics is well beyond the capacity of a short-

term ad hoc committee selected for its familiarity with many fields in NSF's broad portfolio rather than depth of expertise in a single field or few fields. Moreover, the recent experience of DARPA, NASA, and the X-Prize Foundation confirms that choosing prize topics and writing contest rules requires extensive consultation with experts, affected parties, and categories of potential participants to ensure that the prize goals and objectives

- relate to important societal needs and opportunities;
- embody a significant yet achievable advance over the current state of the art and surpass what would be accomplished in the same time frame in the absence of a contest;
- are clear and understandable to the interested community; and
- are stated in an objective, unambiguous way so that there is no doubt whether a particular innovation should qualify as the winner.

There are today no experts on this process comparable to, say, the experts at identifying research opportunities, framing solicitations for or evaluating research proposals, or for that matter, designing financial incentives for private R&D spending.

We believe that topics for smaller-scale, more technical and specialized prize contests can be identified by canvassing specialists in various fields, beginning with NSF's own program managers and peer review panels and incorporating suggestions from scientific and technical societies, federal laboratories, and industrial research managers. Studies identifying research opportunities and priorities in important fields should also be examined for potential prize topics. For a limited number of candidate topics NSF should convene workshops of specialists intimately familiar with the state of the art in the selected fields and related bodies of practice to define a prize objective and criteria for a winning innovation. For the initial set of small-scale prizes recommended, this process can be accomplished within a year so that contests can be announced late in 2007.

For more ambitious prizes a comprehensive systems approach to translating an important societal need into a coherently designed prize goal and specific contest objectives could be helpful. The analysis would identify and describe the principal elements of a complex system, such as carbon-neutral energy supply or an educational system, to locate the critical innovations needed to enable substantial improvements and the obstacles holding them back. These innovations would then become candidates for large-scale inducement prizes. This sort of analysis could be carried out by NSF staff or by expert panels convened by NSF or a

contractor, and the results circulated for comment by interested constituencies. The committee's proposal allows significant time for analysis and refinement before the first major NSF innovation prize contest is announced.

AWARDING INNOVATION INDUCEMENT PRIZES

NSF innovation inducement prizes should be awarded in a manner conducive to raising public awareness of the importance of innovation to the economy and society. Smaller-scale prizes should be awarded in appropriate venues in ceremonies involving the NSF leadership, White House officials, and members of Congress. Larger prizes should be awarded at events, ideally nationally televised, with participation by contestant sponsors, national political and business leaders, and media figures.

1

Prizes in the National Innovation System

PRIZES IN HISTORICAL CONTEXT

A hallmark of contemporary industrial societies is that their governments employ a wide array of public policies to strengthen their national systems of innovation.[1] They do because innovation—the development and adoption of new ways of solving problems and creating opportunities—is universally understood as a powerful contributor to a strong economy, a healthy and dynamic society, and a secure nation.

National innovation policies typically include strong financial support for research and development; funding for higher education in mathematics, science, and engineering; tax and other incentives for private sector innovative activity; a system for protection of intellectual property rights; and consideration of the effects on innovation of policies in such domains as environmental regulation, structural policies (antitrust, incentives for new firm formation), and standards setting.

Governments have also incorporated the awarding of prizes for successful innovation in their arsenal of programs and incentives to encourage innovation. Typically, these are awards recognizing outstanding in-

[1]The concept of a national innovation system has been developed most thoroughly by Nelson. See Nelson, Richard. *National Innovation Systems: A Comparative Analysis*. Oxford University Press, 1993. One of the key tenets of the national innovation system concept is that effective innovation policy almost always involves multiple complementary mechanisms.

novative accomplishments *after* they have occurred and been recognized as such. Inducement prizes—prizes intended to encourage innovators to address defined objectives that the sponsor identifies clearly in advance—have been used only sparingly by governments. There have been a few, relatively high-profile exceptions. A recent book recounted the history of the 18th century prize offered by the British government for development of a successful method for determining the longitude of ships at sea.[2] This prize resulted in development of the ship's chronometer, which revolutionized ocean-going travel and transportation. Much more recently, the U.S. Defense Advanced Research Projects Agency (DARPA) has sponsored a series of prizes awarded to teams that develop programmed land vehicles that can complete a challenging overland course without further human intervention.[3] NASA has recently contracted with several nonprofit organizations to assist it in offering inducement prizes for several relatively small-scale improvements in aerospace technologies through its Centennial Challenges program.[4]

Private interests have been somewhat more active than governments in offering inducement prizes for innovations in various fields. Commercial aviation has featured privately sponsored prizes for many decades. Charles Lindbergh's celebrated solo flight over the Atlantic in 1927 was in response to a prize of $25,000 offered by Raymond Orteig.[5] The privately funded Ansari X-Prize of $10 million was recently won by a team headed by a renowned flyer, Burt Rutan, and Paul Allen, financier and cofounder of Microsoft Corporation. Their team completed a successful pair of suborbital flights in a manned, rocket-powered vehicle, fulfilling the Ansari X-Prize requirements.[6] The National Academy of Engineering (NAE) is administering an innovation inducement prize funded by the Grainger Foundation. The NAE will award $1 million in 2007 to the team that develops the best way to remove arsenic from drinking water obtained from underground sources in developing nations, such as Bangladesh.[7] Prizes have been fairly common in the field of mathematics. In 2000, for example, the Clay Mathematics Institute established a series of $1 million Millennium Prizes for the solution of seven critical problems in mathematics.[8]

---

[2]Sobel, Daval. *Longitude: The True Story of A Lone Genius Who Solved the Greatest Scientific Problem of His Time*. Penguin, 1996.

[3]See *http://www.darpa.mil/grandchallenge/index.asp.*

[4]See *http://exploration.nasa.gov/centennialchallenge/cc_index.html* for a description of the program, the initial array of prizes, and NASA's partner organizations.

[5]Schroeder, Alex. "The Application and Administration of Inducement Prizes in Technology." The Independence Institute, Golden, Color. December 2004, pp. 7-8.

[6]See *http://www.xprizefoundation.com/prizes/xprize_ansari.asp.*

[7]See *http://www.nae.edu/nae/grainger.nsf?OpenDatabase.*

[8]See *http://www.claymath.org/millennium/.*

During the past decade, largely as a result of a 1999 report of a workshop convened by the NAE, interest has grown in exploring ways for the federal government to add inducement prizes to its toolbox of methods for encouraging innovation. The NAE report[9] recommended that federal agencies experiment with the use of innovation inducement prizes. The DARPA autonomous vehicle prize was in part prompted by the NAE support of the concept.

The 109th Congress had under consideration a bill, H.R. 5143, entitled the "H-Prize Act of 2006," that would authorize the secretary of energy to carry out a program to competitively award cash prizes to advance the research, development, demonstration, and commercial application of hydrogen energy technologies. The bill passed the House of Representatives in May 2006.

The present study has been carried out in response to a mandate of Congress in appropriating FY 2006 funds that the National Science Foundation (NSF) establish a program of innovation inducement prizes and that it seek the advice of the National Academies in setting up this program. The specific charge to the NSF and the Academies is discussed below.

STRENGTHS AND LIMITATIONS OF INNOVATION INDUCEMENT PRIZES

Owing to the limited experience with innovation prizes, relatively little is known about how they work in practice or how effective they may be as compared with, for example, R&D grants and contracts, or tax incentives. The theoretical academic literature suggests that not all research problems call for the same incentive instrument. The choice depends on, among other things, the degree to which rewards can depend on cost or on success or failure and the degree to which sponsors rather than researchers can assess research plans in advance.[10] The limited practical experience with prizes underscores the importance of topic selection, prize

[9]National Academy of Engineering. *Concerning Federally Sponsored Inducement Prizes in Engineering and Science*. Report of the Steering Committee for the Workshop to Assess the Potential for Promoting Technological Advance Through Government-Sponsored Prizes and Contests, National Academy Press 1999. On the Web at *www.nap.edu/catalog/9724.html.*

[10]See, generally, Scotchmer, Suzanne. *Innovation and Incentives.* Cambridge, Mass.: M.I.T. Press, 2004, Chap. 2. For a discussion of the strengths and weaknesses of inducement prize contests in the context of climate change, see Newell, Richard G., and Nathan E. Wilson. "Technology Prizes for Climate Change Mitigation," Resources for the Future Discussion Paper, RFFDP 05-33, June 2005.

design, and procedural rules in realizing the claimed advantages of prizes and minimizing or overcoming their alleged limitations.

One of the rationales for a program of innovation inducement prizes at NSF is that such a program will yield a body of experience and evidence that can be mined for lessons about how prizes work and the conditions under which they can be an effective alternative for or complement to other policy instruments. Here we present some general perspectives on the expected strengths and limitations of innovation inducement prizes drawn from the theoretical literature about and past experience with innovation policy instruments. In some cases we suggest comparisons with the more familiar tools of R&D grants and contracts, since the latter—especially grants—are the traditional mainstay of NSF's support of innovation. It is important to recognize that owing to the limited empirical basis for judgments about the use of innovation inducement prizes, these statements stand more as hypotheses to be tested than as empirically supported findings. More than hypotheses, however, they are pointers to the kinds of responses that may be elicited from the various communities that may participate as contestants, supporters, analysts, or commentators. Thus, we believe it is important to have these potential effects in mind as NSF proceeds to implement its prize program:

- Prize programs can focus the attention of policy makers, entrepreneurs, and the attentive public as well as researchers on the goals[11] of an innovation program. They may be less well suited than grants and

[11]Throughout this report we use a variety of similar or related terms to characterize what innovation inducement prizes are about or are intended to accomplish. To avoid confusion we have tried to be consistent in the use of these terms, as follows:

- "Purpose" refers to the motivation for the NSF prize program as a whole to strengthen the nation's capacity for innovation;

Other terms refer to particular prize contests:

- "Goal" refers to the societal interest being served by a prize (e.g., reducing pollution);
- "Objective" refers to a concrete statement of what a particular prize is for, (e.g., to develop a benign substitute for a polluting chemical). (Note that we also use "objective" as an adjective, meaning requiring little or no subjective human judgment.)
- "Topic" refers to the field of inquiry of a prize or category of technology of a particular contest (e.g., "green" chemistry).

Finally,

- "Near-term impact" refers to the subsidiary purposes of prize contests, correlates of successful administration that can be measured and evaluated, such as attracting diverse participants in the competition, involving students and young professionals, inducing private parties to support contestants, stimulating public interest in science and technology, and enhancing the public reputation of the prize-giving institution.

contracts to the development of basic scientific and engineering understanding underlying the achievement of goals.

- Prizes, like peer-reviewed grants, can shift the origin of ideas for innovations to address a particular goal away from the federal government toward the nongovernmental performers who carry out the related research and development.
- Prize programs can instill in the innovator a single-mindedness and focus regarding the need to accomplish the objectives set out in the prize contest.
- Prize programs can stimulate a high degree of competition among the teams that undertake to pursue a prize. Although this is often a virtue, it can be wasteful if the prize chosen is too large.
- Prize programs are likely to attract as contestants an array of individuals and organizations that is somewhat different from the scholars and academic institutions that typically apply for NSF grants. Compared with grant or contract programs, prize programs impose fewer demands on contestants by reducing or eliminating the requirement for *ex ante* demonstration of the capability to succeed and by eliminating the administrative burden of accounting for expenditure of public funds, whereas prize programs impose a greater burden on participants to raise private funds to support their participation in the contest. Thus, compared with grant programs, prize programs may be expected to attract more individuals, informal teams, and for-profit firms of various sizes and perhaps not as many academic institutions.
- Prize programs, compared with grant and contract programs, can attract more interest from the general public, conceivably encouraging support of and participation in the science and engineering enterprise.
- Prize programs can create incentives for nongovernmental organizations and individuals to invest financial resources in support of the activities of prize contestants, and these investments may exceed the value of the prize purse to be awarded to the winner. If the incentives for nongovernmental investments are sufficiently strong, the sponsoring agency may need to expend only the amount of the prize purse plus the costs of contest administration, while all the costs of research are paid for by nongovernmental parties.
- The requirement in a prize contest that would-be innovators fund the research up front may inhibit participation by entities that do not otherwise have access to discretionary funding for innovative activities.
- Prize programs are likely to inhibit the exchange of information among researchers and other innovators, at least for the duration of the contest, while sponsors can condition research grants or contracts on information sharing.
- Although prize programs may involve students as members of

competing teams, they tend to put less direct emphasis on the education and training of the next generation of researchers, which is often an important outcome of research grant programs.

- For academics, prize programs tend to substitute expectations of financial rewards and public acclaim for the traditional reward of enhanced professional reputation.
- For many topics or fields of interest it may be difficult to identify a set of conditions for winning that would make for a sensible prize contest.

As this brief discussion of the potential strengths and limitations of innovation inducement prizes indicates, prizes offer some advantages over grants and contracts while also having some disadvantages. A program to explore the potential utility of such prizes at NSF offers an unprecedented opportunity to try various approaches to such prizes, to gather systematic data on the prize process and its outcomes, and to learn more about where prizes have the greatest payoff and about where they may work best as substitutes for or complements to grant programs.

NSF ENGAGEMENT IN INNOVATION INDUCEMENT PRIZES

In the FY 2006 appropriation for NSF the House Appropriations Subcommittee on Science, State, Justice, and Commerce sent a strong message to the NSF that it should establish an innovation inducement prize program. The bill as enacted said simply,

> [t]hat funds under this heading may be available for innovation inducement prizes.[12]

The subcommittee went further in House Report 109-118 accompanying the bill:

> The recommendation includes language that allows funds provided under this account to be available for innovation inducement prizes. The concept of inducement awards to encourage broad involvement in solving a specifically stated scientific problem has been a catalyst for scientific advancement since at least the early 18th century. In 1999, a National Academies workshop on this topic encouraged federal agencies to make more extensive use of this mechanism to pursue particular scientific and technological objectives. The Committee expects NSF to engage the National Academies to craft a prize or categories of prizes that would be of

[12]H.R. 2862, Science, State, Justice, Commerce, and Related Agencies Appropriations Act, Fiscal Year 2006 (Public Law 109-108), National Science Foundation, Research and Related Activities account.

> an appropriate scale and to develop the rules and conditions for awarding prizes, and to report back to the Committee on plans to initiate a prize program in fiscal year 2006. The Committee strongly encourages NSF to use this mechanism, particularly in programs that specifically emphasize innovation, to focus on high risk/high payoff research projects. The Committee also expects NSF to encourage private sector involvement in the effort to create a prize program.[13]

The brief provision of law, agreed to by the Senate and signed by the President, allowing NSF to spend appropriated funds on innovation inducement prizes, along with the guidance in the House Appropriations Subcommittee report on how to use the funds, poses a substantial challenge to NSF. From its establishment in 1950 NSF has been seen and has seen itself as an agency that works principally through the competitive award of grants to academic scientists and engineers for self-initiated proposals about how to advance basic understanding of natural and social phenomena. In 1968 NSF's role was broadened somewhat to make explicit that it also has a responsibility to make similar awards for applied research, although NSF has exercised this authority with greater or lesser ease at various times. NSF has a few award programs, notably, the Waterman Award for outstanding achievement by a young scientist or engineer, but in no previous case known to the committee has NSF employed an inducement prize program to encourage innovation in basic or applied research.[14] Clearly, NSF will need to take full advantage of the limited contemporary experience with innovation inducement prizes at DARPA and NASA (see below) as well as in the private sector.

In its guidance to NSF, Congress indicated that it wanted NSF to develop a program of "innovation inducement prizes" and "to use this mechanism . . . to focus on high risk/high payoff research projects" in the pursuit of "scientific and technological objectives." This guidance sug-

[13]House Report 109-118, Science, State, Justice, Commerce, and Related Agencies Appropriations Bill, Fiscal Year 2006, p. 111.

[14]Ours is not, however, the first proposal that NSF *investigate* the use of prizes to stimulate innovation. After the termination of the federal supersonic transport development (SST) program in 1971, President Nixon ordered a comprehensive review of the nation's policies affecting innovation. The effort was headed by William McGruder who directed the SST program at NASA. One of the outcomes was the National R&D Assessment (RDA) Program at the NSF, a small-scale sponsor of studies of the economics, processes, and outcomes of innovation. The original draft agenda of research, dated November 1, 1972, listed the following as one of six key issues under the policy studies part of the program: "Prizes: To what extent have prizes been effectively used by governments to stimulate R&D and innovation? What standards have been used to make awards, and how has the value of awards been set?" So far as we know, the RDA program did not undertake any research along these lines.

gests that Congress had in mind that prizes would be offered not only for what in the management and economics literature is considered "innovation" (namely, the commercialization of new products, services, or processes) but also for major advances in the core of scientific and engineering knowledge that can enable such useful technological advances in the future. We encourage NSF to adopt this broader notion of innovation.

NSF faces a further challenge in setting up an innovation inducement prize program to focus on problems of national importance because it has not generally been viewed as having a charter to support innovations intended to address societal needs. Such responsibilities have been given to agencies with specific spheres of responsibility, such as space exploration (NASA), defense (DOD), energy supply and utilization (DOE), health (NIH), and agriculture (USDA). By contrast, the rationale for the establishment and operation of NSF, going back to the arguments for a National Research Foundation advanced by the Bush report in 1945,[15] has been that the financial support of undirected basic research in all major fields of the natural and social sciences and engineering would in the long run be the most effective way for the federal government to support innovation for national needs. To be sure, NSF is constantly aware of society's needs and aspirations as it designs its research support programs. However, only rarely, and then usually with controversy, has NSF engaged in direct support of research intended to generate innovations of immediate use to society.[16]

Innovation inducement prizes are generally thought to have the greatest promise in encouraging scientific and technological advances to address national goals and opportunities. To some extent, then, an innovation inducement prize program that includes prizes for applied research

[15]Bush, Vannevar. *Science the Endless Frontier: A Report to the President*. Washington, D.C.: Government Printing Office, 1945.

[16]Perhaps the most well known such effort was NSF's program of Research Applied to National Needs (RANN), which operated during the middle 1970s. While one can point to a number of important lines of research and innovation that were initiated and nurtured by RANN, including programs in solar energy and energy conservation that were transferred to the Department of Energy after its establishment in 1977, RANN was widely viewed in the academic research community as a misdirection of NSF's resources away from NSF's proper mission. NSF has approached such programs with great care since. In more recent times NSF has fielded a number of programs that have the indirect or very general support of innovation as one of their goals, including the SBIR (Small Business Innovation Research), ERC (Engineering Research Centers), STC (Science and Technology Centers), and PFI (Partnerships for Innovation) programs. None of these programs, however, has been organized around encouraging innovation toward specific societal goals or needs specified in advance by NSF.

and development outcomes will demand of NSF a broader than usual understanding of the scope of its mission relating to innovation.

The committee recommends that NSF embrace the House Appropriations Committee's challenge as an opportunity to explore a new mode of research and innovation support that may prove valuable for the country as well as for the agency. It is by no means clear that the founders of NSF more than a half century ago appreciated fully the range of mechanisms that NSF could productively employ in mobilizing the nation's scientific and technical talent in the exploitation of the "endless frontier" of science. Experimentation with an inducement prize program, like all good research, will yield both anticipated and unanticipated outcomes, some positive and some not so positive. It is with this perspective in mind that the committee offers in the remainder of this report a set of observations and recommendations on the establishment and operation of an NSF innovation inducement prize program that, at least at the outset, will be experimental.

2

An Experimental Innovation Inducement Prize Program at NSF

OVERVIEW OF AN EXPERIMENTAL PRIZE PROGRAM

In view of the NSF's lack of experience and the federal government's limited experience in the design and administration of prize programs intended to induce innovation of national significance, the committee recommends that the agency take an experimental approach to implementing the congressional directive to award such prizes, especially during the program's formative period.[1] By an "experimental program" we do not mean that prizewinning would necessarily entail use of experimental methods or that the program would be set up as a rigorous scientific experiment with appropriate controls. We mean that the program should be conducted with careful attention to evaluation, measurement, and use of feedback about the program itself. There is much to learn about how to determine the appropriate goals and objectives for inducement prizes,

[1]There is precedent for an experimental approach to innovation policy. For example, in the early 1970s interest emerged in using federal procurement to induce technological innovations thought to be of national importance. One prominent response was the Experimental Technology Incentives Program, or ETIP, implemented by the National Bureau of Standards (now National Institute of Standards and Technology, or NIST). ETIP sought to learn how to redesign procurement processes so as to strengthen the incentives for potential suppliers to develop new and improved technologies that were not available in the commercial or governmental marketplaces. See Lewis, Jordan D. "Incentives for Technological Change, A Progress Report." Experimental Technology Incentives Program. March 26, 1975.

how to set the terms and conditions under which prize contestants are recognized, establishing an effective time frame for award of a prize, whether and how to partner with or outsource prize administration to nongovernmental entities, and a number of other issues discussed in this report. To reduce these uncertainties as well as to contribute to innovation, NSF should proceed with care in implementing an inducement prize program, beginning relatively modestly and learning as experience in designing and implementing prizes is analyzed and accumulated. Proceeding in this way need not delay program implementation. In fact, we recommend that NSF initiate a few somewhat specialized prize contests relatively quickly while preparing for more ambitious prizes to follow.

The notion of a prize program as a learning opportunity carries with it the obvious corollary suggestion that NSF offer several prizes—on the order of 5 to 10—under its initial program. Multiple prizes offer an opportunity to try various contest designs and administrative approaches.[2] They also afford an opportunity to build public interest in the program by making relatively modest awards for successful shorter-term efforts while allowing enough time for more significant, longer-term contest objectives to be reached. Within an experimental program early progress can be made on relatively straightforward approaches to contest administration, leaving time for later development of more complex contests and mechanisms.

In the following sections the committee outlines an approach to the design of an inducement prize program that emphasizes learning and program improvement in the formative years, leading to more ambitious contest goals with greater visibility and higher stakes for participants and NSF. The program would fund prizes in several fields of endeavor that differ with respect to the scale and scope of the prize, the timing of its

[2]The committee suggests a program of this scope based largely on three considerations. First, the number of prizes should be large enough to allow for some variation in the parameters of the various contests to facilitate learning from the program's experience. Second, we expect that mounting each prize contest will be a substantial intellectual and administrative challenge that will draw heavily on NSF staff and advisory resources, which suggests keeping the number of prizes manageably small. Third, we have some concern that a large number of prizes might detract from the prize program's goal of focusing on high-priority national need. To the extent that financing activities to compete for a prize will depend on corporate sponsorships, philanthropy, and volunteer efforts, it will be important to understand whether the pool of such resources for supporting contestants is limited. The interest of the general public in such contests may also be limited. Thus, during program evaluation, NSF should assess the degree to which each subsequent contest attracts contestants and sponsors.

announcement, the duration of the prize contest, how winners are determined, the engagement of expert and interested groups, and other factors. In the remainder of this chapter a number of issues in the design of such a program are discussed and preferred alternatives suggested. The next chapter discusses a process and criteria for selecting some initial prize topics. It discusses several potential prize topics to illustrate selection processes and criteria.

ADMINISTRATION AND DESIGN ISSUES

We begin with a general description of an innovation inducement prize program and then discuss a number of specific issues regarding such a program.

The committee recommends that NSF establish a multiyear, continuing innovation inducement prize program. NSF should assume primary responsibility for the design and implementation of the program. NSF should also take full advantage of the interests and capabilities of other federal agencies as well as of diverse private parties, when appropriate enlisting them as partners in the program. NSF should consult widely with professional and technical societies, industry associations, entrepreneurs and investors, industrial R&D managers, public interest organizations and others in designing and implementing the prize contests it sponsors. NSF should experiment with a variety of types of prizes, as discussed below, as well as with the mechanisms used to induce a wide range of contestants to pursue the prize awards.

The committee envisions that, at least initially, the funds used to pay for the prize awards (i.e., the prize purse), as well as those needed to administer the prize program contests, will be appropriated for these purposes by Congress. Such funding should be in addition to rather than a substitute for funds appropriated to NSF in support of research and education in science, mathematics, and engineering. As indicated above, the committee anticipates that in addition, contestants will undertake private investments in the research and development activities entailed in competing for the prizes. The magnitude of these investments will depend on the nature of the prize objective and the opportunities for publicity and other benefits, among other factors. The committee does not believe that the primary reason for government sponsorship of a prize contest is to save taxpayers' money relative to the cost of accomplishing the objective through a grant program or procurement. Rather, the primary reason for offering a prize is to attract different parties to contribute to a recognized societal or scientific objective.

The NSF program should offer prizes in a range of fields to address a diverse set of national challenges. Prizes would differ substantially in

size and be administered in several ways. All of the prize contests would follow a common set of general administrative rules. Each contest would have a set of rules tailored to the specific circumstances, as discussed below.

"First-past-the-post" and "Best-in-class" Contests

There are two principal types of innovation inducement prize contests. The more familiar type is the "first-past-the-post" contest, in which a prize is awarded to the first team[3] that accomplishes a stated objective in accord with the contest rules.[4] Such a contest may be held open for as long as required for a winner to emerge or it may end at a date certain. In either case, we suggest that NSF award prizes using a "first-to-achieve" rather than a "first-to-report" rule. In the latter case, if no team reaches the objective by the contest termination date, no award is given. The committee believes that contests of finite duration are generally preferable, although the lead time can be quite long depending on how ambitious the scientific or engineering challenge is. A second major type of contest is the "best-in-class" contest, in which the winning team is the one that comes closest to achieving a stated objective within a specified time period. For a best-in-class contest, one option is for the rules to specify a minimum level of accomplishment; and if no team reaches that minimum, the prize will not be awarded.

In both types of contest, entries may be evaluated on the basis of objectively measurable outcomes or the judgments of expert panels. Contests designed around objectively measured outcomes are less subject to influence and controversy about outcomes and in the committee's judgment are generally preferable, although we recognize that this may not always be feasible if the range of possible solutions to a challenge is broad.

A contest may be structured to award a prize only for accomplishing the final contest objective. In an especially challenging contest, progress may be enhanced by awarding a series of prizes to recognize accomplishment of intermediate objectives. In such contests, award of intermediate prizes may also be conditioned on meeting preset minimums of performance.

Other important features of inducement prize contests include the

[3]We use the word "team" throughout to denote an individual, an organization, a group, a partnership or any other entity that participates in an inducement prize contest.

[4]To minimize priority disputes, contest rules may have to specify how progress is to be documented.

breadth and significance of the societal need that informs the contest goal and objective, the anticipated degree of innovative advance needed to accomplish that goal, and, of course, the size of the prize purse. The form of the prize award can also vary and can range, for example, from a cash prize to a procurement contract.

The committee recommends that NSF consider a variety of contests that would represent different kinds of challenges, feature different award levels, and test different contest designs. Some contests would reward accomplishment of simple and clear-cut, albeit challenging scientific or technical objectives, which if realized, would open the door to a number of important innovations in the future. The objectives of such contests could be stated in objective, quantitative terms, and it would likely make sense to set them up as first-past-the-post contests. Prizes could range from $200,000 to perhaps $2 million each. NSF could initiate its prize program by announcing three or four such contests each in a different field, during the first two years of the program. Depending on experience with these contests, NSF could then offer one or two additional prizes of this type each year thereafter. Exclusive of administrative and support costs,[5] this part of the recommended program could require an initial prize award budget of $800,000 to $8 million, and perhaps $400,000 to $4 million per year on an ongoing basis thereafter.

Other NSF contests should offer considerably larger awards to encourage innovations that address significant economic, social, or other challenges to the United States. They would likely elicit much more ambitious and competitive responses from contestants than would be expected from the prizes at lower levels. Prizewinning innovations would likely be highly complex and expensive, would address objectives well beyond the current state of the art, and be intended to become integral to major changes in complex sociotechnical systems such as those of energy supply, environmental protection, education, or health care. Setting objectives for such contests would likely involve the considered judgment of multidisciplinary groups of experts, just as reaching the objectives could

[5]NSF funds personnel and related costs from a separate account not rolled into program budgets. Typically, these and other administrative costs are a small proportion of program costs, about 7 percent on average. In the case of the prize program, in-house personnel costs (for, say, a program director, two professional staff, and one administrative staff) would be modest; but the cost of planning and consultation to determine the topics of prize contests, advertising the contest to a wide range of potential participants, and ongoing evaluation could push administrative costs higher than the average for NSF programs, whether or not these functions are contracted out.

require the efforts of large teams with contributions from many disciplines and fields of expertise. The prizes in contests of this type could range from $3 million to perhaps $30 million each. Designing a contest at this level would probably require one to three years of preliminary planning, consultation, and analysis. NSF might offer one new contest of this magnitude every few years, and each contest would be planned to continue for 5 to as many as 10 years. Thus, this part of the program would entail a budget for prize purses of $5 million to $50 million annually at steady state, exclusive of administrative and supporting costs, depending on the number of contests offered and the prize for each.

With either scale of prize contest the objectives should be stated in objective, measurable terms, and the committee generally prefers the first-past-the-post format. Nevertheless, depending on the nature of the objective and expected technological advance, either small or large contests could incorporate subsidiary best-in-class prizes for accomplishment of an intermediate objective.

The small- and large-scale prize contests suggested here represent what the committee believes are reasonable bounds on the scope of prizes that it would make sense for NSF to offer. They were selected for purposes of exposition of the design choices and their implications. We can envision that other intermediate types of prize contests will evolve as NSF gains experience with an innovation inducement prize program. A few potential topics of both small- and large-scale prize topics are described in Chapter 3.

We turn next to a discussion of a number of prize program design issues, including program administration and funding; the roles of NSF, other agencies, and the external communities; selection of prize topics and contest objectives; contest rules; and program evaluation.

NSF's Role in Program Administration and Funding

NSF should take primary responsibility for developing and implementing the innovation inducement prize program. However, there are a variety of opportunities to make full use of the interests and capabilities of other federal agencies and a number of private sector entities in the profit and nonprofit worlds. Here we address the role of the NSF and how other institutions could be engaged in the NSF prize process.

Because NSF will be accountable to Congress for the conduct of the prize program and its results, the committee is of the view that NSF must execute certain tasks itself. For each contest NSF should decide on the topic or focus, set the rules, and be responsible for deciding the winners. NSF will also determine whether and how other entities contribute to the program's design and administration. NSF will seek annual appropria-

tions, request any needed changes in authorizing legislation, and report on the program's status and progress to Congress and the general public.

To perform these functions NSF should establish an innovation inducement prize program staff, which we will call here the "Office of Innovation Prizes" or OIP. OIP could be set up using existing program and administrative support staff, perhaps augmented by one or two new hires or individual consultants or contractors experienced in prize administration. OIP should be able to call on the program directorates and staff across the NSF for scientific and technical expertise to help with contest design and with evaluation of prize applications and submissions. OIP would plan the prize program, manage contractor selection and oversight, ensure that contractors carry out the prize program tasks in conformance with all relevant governmental rules and regulations, and administer a process of formative and summative program evaluation on behalf of the director and the National Science Board. OIP would also be the focal point for interagency participation in prize contests for which NSF determines that such participation is desirable.

The decision to award a prize should be made by the director of NSF upon recommendation from the OIP. The decision of the director in any particular prize contest on the technical merits of applications should be final, but a mechanism for appeal on procedural grounds needs to be provided.

The director, acting through OIP, should establish a formal external advisory committee on innovation prizes that would include leading scientists and engineers, experts in the innovation process, people with some experience in inducement prize implementation, and such others as the director views as appropriate. The advisory committee would do just that, advise; it would not have a role in the decisions to award specific prizes to specific winners. Ad hoc, contest-specific committees of expert advisors could be convened to participate in or verify award decisions.

The committee recommends that NSF request and Congress provide separate "no-year" budget authority for funds to support the prize program awards. NSF would be barred from using these funds for purposes other than the prize program unless agreed to by Congress. No-year budget authority would help ensure that funds remain available to make occasional large prize awards when multiyear contests are completed.

At present the legislative authority for the NSF innovation inducement prize program is limited to guidance from the House Appropriations Committee in the FY 2006 Science, State, Justice, and Commerce Appropriations bill and associated committee report language. In the committee's view it will be important to the long-term success of the prize program, including its financial stability, for NSF to seek formal authori-

zation of the program from Congress in addition to the encouragement it has received from the Appropriations Committee.

A broad reading of the NSF Act of 1950 suggests that operating a prize program is within the NSF's general authority to spend funds in support of innovation, and the committee believes that the agency can proceed with the first set of prize contests on that basis. NSF was established as an agency whose principal mode of operation was to make grants and enter into contracts for the support of research and of education in scientific and engineering fields. Adding authority to make prize awards, and to do so in cooperation with private entities, would ensure that the NSF has the full support of Congress in carrying out such programs. Authorizing legislation could also be considered, if necessary, to modify Section 1870(f) of the NSF Act to allow NSF to accept donated funds that are intended to support the prize program or a particular prize.[6]

The committee cautions against seeking legislative authority for the prize program that is overly detailed and prescriptive as to the topics of prizes, size of prizes, types of contestants, rules for competing, and so on. NSF needs the flexibility within broad legislative grants of authority to experiment with the design and administration of a prize program if it is to be successful.

Role of Non-NSF Entities in Program Administration and Funding

We anticipate that teams from the private sector and nonprofit institutions will be the principal contestants for innovation inducement prizes. Entities other than NSF are expected to fund most if not all of the research and related activities that contestants conduct in pursuit of the prizes. In designing a prize program, it is important to take into account the likely motivations for nongovernmental entities to provide financial and other resources to contestants to ensure that the program as designed is responsive to the potential of those motivations. Several motivations were identified by the committee, including the following:

Some for-profit firms may compete for the prizes or support the research of other contestants in the expectation that they will be able to profit from commercialization of the research results, regardless of whether the contestants they support actually win a prize. For such firms

[6]Section 1870(f) of the NSF Act permits NSF to accept and use donated funds, but only "if such funds are donated without restriction other than that they be used in furtherance of one or more of the general purposes of the Foundation." It is not clear whether this language would allow NSF to accept funds donated specifically for the prize program or a particular prize.

the monetary value of the prize may be of relatively limited consequence; the much greater reward would come from profits earned in the marketplace and from publicity associated with the contest and with winning teams. To enjoy such rewards these firms need to own or control the commercialization of any intellectual property, including trade secrets that are developed in pursuit of a prize.

Another motivation for private support of prize-seeking R&D is that supporters may hope to benefit from being recognized as supporters of a research team. In a sense, supporting an R&D team that is pursuing an NSF prize would constitute a form of advertising not unlike that associated with financing of sports teams or athletic events. A supporter motivated in this way may have little or no direct interest in exploiting prizewinning innovations. Instead, it expects to benefit from the association with the celebrity of competing teams. For this kind of supporter, prize contests need to be organized in such a way that the public relations aspects of the contest are managed to their benefit.

Yet another motivation for private support of contestant teams is the supporter's commitment, personal or corporate, to the goal of a particular contest. Such a supporter may be more interested in seeing that the goal is achieved than that any particular team achieves it. This type of supporter may even be willing to augment the prize purse offered by NSF. Nonprofit foundations and wealthy individuals may assume this role; they may not be interested in bringing attention to themselves through a prize contest—some may even prefer to remain anonymous. For this kind of supporter, the structure of the contest objective is its most important aspect.

We anticipate that colleges, universities, and other nonprofit organizations will be active supporters of teams competing for some NSF innovation inducement prizes, either using discretionary resources or teaming with for-profit entities. For example, some of the leading participants in the DARPA autonomous vehicle prize competition (including the 2005 grand challenge winner) were university-automotive firm partnerships. In addition to the possibility of using the publicity associated with the contest to raise private funds in support of their contestant teams or for other research purposes or simply to help recruit faculty or students, educational institutions may see involvement of student and faculty teams in innovation prize competitions as an exciting and creative educational experience for students, especially those enrolled in engineering, design, or problem-solving courses. Educational institutions may view team sponsorship as a useful means of marketing to potential students, research collaborators, and donors. For them, excitement, team participation, and photo opportunities may be the most salient benefits of supporting competing teams.

NSF should look to a variety of external entities to assist in aspects of prize program design and administration. Innovation inducement prize contests have typically focused on goals that may be the responsibility of other agencies, such as National Institute of Health (NIH), Department of Energy (DOE), Department of Housing and Urban Development (HUD), Department of Transportation (DOT), Department of Justice (DOJ), or Environmental Protection Agency (EPA). We recommend that, in cases where it is determined to be appropriate for NSF to award a prize related to another agency's portfolio, NSF consult with the agency in developing the terms of the prize. In some cases it may be desirable for NSF to partner with another federal agency to offer a prize. Such partnerships may be especially productive when the collaborating agency does not have a strong R&D program of its own and could benefit from NSF's access to scientific and engineering expertise.

NSF should consult widely with professional and technical societies, industry associations, venture capitalists, industry research managers, public interest organizations, and others in identifying potential prize topics. These kinds of groups can help in identifying key unmet needs in their areas of expertise and in understanding how particular constituencies may respond to contest designs. In some cases associations have developed "road maps" of R&D priorities that may be useful guides to selecting prize topics. The same kinds of organizations may be useful conduits for disseminating information about new contests and may help NSF reach beyond its traditional academic constituencies.

The committee recommends that NSF experiment broadly with new mechanisms for outreach to communities with ideas for prize topics, especially to communities beyond the ones NSF usually reaches. For example, Web sites, blogs, and chat rooms are tools that can be used to reach specialized constituencies. NSF could fund workshops organized by various kinds of organizations to identify important prize topics. It could even offer rewards for the best ideas for prize contests.

There may be important benefits to NSF in contracting through the Office of Inducement Prizes with one or more external organizations to assist in designing and, even, administering some aspects of each prize contest, perhaps with different organizations under contract for each prize. These organizations would bring specialized expertise to bear in crafting the technical rules necessary to specify the objective of each of the prizes or in judging whether a contest objective has been met. To help design a prize NSF could contract with scientific and technical societies whose members have deep knowledge of the technical domain in which a prize is offered. NSF could also contract with organizations experienced in designing and offering innovation inducement or other kinds of prizes to help administer a contest.

Apart from providing technical expertise, contractors may be able to engage in fund raising in support of the awards, a role that may not be comfortable for NSF or even permitted under current law.[7] The contractor model could also facilitate employing a range of professional expertise not generally associated with NSF, such as major prize administration, media management and outreach, marketing and branding, and outreach to potential contestants in sectors that NSF does not normally reach.

The Intergovernmental Personnel Act could provide a useful vehicle for NSF to obtain on a limited-term basis the staff services of individuals who are experienced in prize design and administration.

The committee recommends that NSF make use of external contractors in whatever ways will enable it to move most expeditiously and effectively to mount a vigorous innovation inducement prize program.

Selection of Prize Topics, Goals, and Objectives

NSF should decide on the prize topics, goals, and objectives for each contest. The Office of Inducement Prizes would manage the selection process, reaching out widely to both generalist and specialist expertise in doing so. NSF should select the first set of prize topics and goals within a few months, although detailed contest objectives and rules may take more time to develop.

Following announcement of the initial set of prize contests, the committee envisions a more extended process for selecting the more ambitious prize topics, determining the prize goals within those topics, and designing the objectives of each contest to best match the circumstances that surround likely goal achievement.

INDUCEMENT PRIZE CONTEST RULES

Innovation inducement prize contests would be governed by a number of rules. Broadly, these can be divided into (1) administrative rules that would apply generally to all such contests sponsored by NSF and (2) rules that would be specific to each contest. Here we discuss and offer recommendations regarding some of the most important of these rules.

We suggest two caveats at the outset. First, since one purpose of the innovation inducement prize program is to open federal support to entities that have not traditionally received NSF funding or even federal fund-

[7]See footnote 6 for what the NSF Act says about NSF acceptance of donated funds.

ing more generally, it is important that the rules be kept as limited and as simple as possible. Second, we are aware that variations in these rules will undoubtedly be desirable in certain cases, and we counsel against adopting rigid rules that are difficult to tailor to circumstances. As a general principle, the committee recommends that NSF make the rules no more restrictive than for other NSF funding mechanisms, and perhaps less restrictive in cases where NSF believes that would be appropriate to the prize instrument.

Administrative Rules Applicable to All Contests

NSF should consider adopting a number of program rules or guidelines that would apply uniformly to all such contests. NSF should consult with the prize program advisory committee and other interested parties to ensure that these rules are consistent with the best understanding of what is needed to make prize programs effective; and once they are formulated, NSF should consider incorporating them in a prize policy manual analogous to the NSF Grants Policy Manual. General rules are needed to govern registration, eligibility, appeals of award decisions, contest termination decisions, and control of intellectual property.

Contestant Registration

After a prize contest is announced, teams would be given a finite but reasonably generous window of time in which to register with NSF or its designee their intention to compete for a prize. A period of six months to as many as three years after contest announcement is reasonable, depending on the details of the contest requirements. Registration should identify the principal participants in teams, including the team leaders and his or her affiliations. Registration would, at a minimum, acknowledge team understanding of and agreement to abide by contest rules, including acceptance of the decisions of NSF regarding prizewinners. We do not foresee a general need to prequalify contestant teams, although this may be required if competing would require access to specialized federal resources. A key advantage of registration is that it would provide NSF an early indication of the likely interest in pursuing a particular prize and possibilities for early publicity.

Some inducement prize contests have required payment of an entry fee both to defray part of the cost of prize administration and to discourage frivolous applications. The committee recommends against charging such fees at initial registration, especially since one purpose of the prize program will be to encourage the widest possible participation, including

by teams that may have limited resources, such as independent inventors and students.

Compliance with Applicable Regulations

The registration procedure should include a statement of intent to comply with all applicable regulations in carrying out experiments or tests in pursuing a prize. NSF should beware of creating excessive red tape around such certifications, but some due diligence to ensure the legitimacy of contest winners would be prudent. On the other hand, with the exception of requiring documentation of progress toward a contest objective in a manner subject to verification, the kinds of cost-accounting and recordkeeping standards imposed on recipients of federal grants and contracts should not be applied to prize contestants, since there is no public need to account for the contestants' use of private sponsor funds or for the winners' use of the contest award funds.

Conflicts of Interest

The issue of conflict of interest may arise in connection with NSF's (or any other government agency) offering inducement prizes for accomplishments in areas in which it also awards grants. It has been suggested that an agency could favor its own grantees or contractors in determining which team has actually won. In the committee's view, however, if the rules for determining winners are well written and the criteria for winning are stated objectively, it should not be possible for the awarding organization to bias the results in favor of "its" teams. As NSF is the principal supporter of research in many fields, it would be contrary to the purpose of a prize program to exclude the best researchers because they happened to have received a grant award from NSF in a related area.

Indemnification

We believe it is not necessary to ask contestants to sign waivers indemnifying the NSF for any legal liabilities that arise from the research, testing, or commercialization of an innovation developed in pursuit of a prize. As a federal entity, NSF is protected from most liability actions. Many applicants of the type NSF would wish to attract would not likely possess the resources that would be required to make any such indemnification meaningful. The cost of insurance to contestants for protecting the government against liability actions may also be prohibitive for such entities.

Foreign Participation

A key issue in designing the contest rules is whether a prize could be awarded to persons or organizations outside the United States or who are not citizens or permanent residents of the United States.[8] We note that NSF has statutory authority to make grants and other awards to non-U.S. persons and entities, but that it can do so only with the advice and approval of the Department of State.[9] On the other hand, NSF funds awarded to U.S. institutions are commonly used to support research carried out in those institutions by noncitizens, including temporary residents, such as foreign graduate students and visiting researchers. Under certain conditions NSF permits its grantees to make sub-awards to non-U.S. entities. Thus, the law governing NSF's activities does not bar supporting foreign persons or entities.

Although non-U.S. entities could be accommodated as prize contestants on the same terms as those that are applied to other NSF award programs, there are other considerations. Foremost is the fact that one purpose of the NSF innovation inducement prize program is to strengthen domestic U.S. competitiveness. Opening the prize competitions to non-U.S. entities could conflict or appear to conflict with this purpose. Awarding a prize for a technical advance that may ultimately be commercialized is not the same as supporting fundamental research with the intention that the results be available to all.

We recommend that eligibility for NSF's innovation inducement prizes be limited to U.S. entities, for which the appropriate test is whether the institution or organization with which the applicants are associated is incorporated or registered in the United States and whether the winning team, whether affiliated with such an institution or independent, is led by U.S. citizens or permanent residents. This policy would allow for the participation of the U.S. subsidiaries of foreign-owned companies as well as the participation on U.S.-led teams of immigrants with student or work visas.

Federal Involvement

Another important issue is whether applicants may include federal employees or use federal funds or facilities in competing for an innova-

[8]This section does not take into account the possibility that as experience is gained with the inducement prize programs, it may prove worthwhile for NSF to consider partnering with one or more other countries to offer inducement prizes on an international basis. Consideration of the pros and cons of this approach was beyond the scope of this study.

[9]42 USC 16, Sections 1870 and 1871 (portions of the NSF Act).

tion inducement prize. We recommend that federal employees not be eligible to lead or directly participate in teams competing for the prize.[10] Organizations substantially funded by the federal government on a sustained basis, such as Federally Funded Research and Development Centers and Government-Owned, Contractor-Operated federal laboratories, should not be eligible to sponsor competing teams. Federal facilities could be used and federal laboratory expertise could be tapped by nonfederal entities if they are made available for use by all teams on an equitable basis.[11] We recommend against banning the use of federal funds in doing research toward a prize, in part because segregating funds by source and purpose is a difficult practical matter in large organizations, and in part because we see no principled reason for barring use of such funds. In fact, NSF may chose to mount a mixed program that would offer both grants to participants chosen on a competitive basis and a prize for the most successful research result.

Early Termination of Contests

NSF should reserve the right to terminate a prize contest before a winning team appears if, in the sole judgment of NSF, an entity that did not register to participate in a contest had, in fact, developed an innovation that would win the prize had it registered. This could happen, for example, if a foreign entity that was not eligible for the U.S. competition were the first to succeed, or if a U.S. entity that chose not to enter the contest or that made its innovation after the registration period had closed was the first to succeed. While contest termination may be unsettling for NSF and the registered teams, it is certainly preferable to having to award a prize to a team demonstrably not best in class or first to achieve the contest objective. Contest rules should specify how NSF would acknowledge the accomplishments of the noncontestant entity and how it would notify contestants in the event of contest termination.

Appealing Award Decisions

As noted earlier, it is the committee's view that because of the unusual nature and high visibility of the program, final determination of

[10]This ban on participation should be absolute for employees of NSF. The rules may allow for participation by employees of other federal agencies and contractors on their own time if such activity would be otherwise consistent with their employment agreements.

[11]"Equitable" does not necessarily mean "equal." For example, a user fee for testing a prototype at a major federal laboratory could be charged to large corporations but be waived for small firms, academics, student groups, or independent inventors.

prizewinners should be made by the director of NSF and that the decision of the director on whether a particular innovation achieved the contest goal should be final. For the rare instance in which an award is challenged on procedural grounds, the NSF should provide an appeals mechanism.[12] The general contest rules should spell out the procedures for filing and hearing such appeals.

Intellectual Property

We recommend that the federal government not seek to own or control the disposition of intellectual property developed by contestants in the course of seeking NSF innovation inducement prizes, with one exception. The exception would be that if the winner of a prize chooses not to put the winning innovation into commercial practice within a reasonable time period and if it declines to license it to another U.S.-based entity wishing to commercialize the invention, the winner would be required, as a condition of the award, to enter into good faith negotiations with the other party for a license to be awarded under terms and conditions typical for the industry or technology sector. A winner could avoid even that limitation on its exercise of its intellectual property by foregoing the prize purse.

The committee counsels against any requirement that the winner make the intellectual property underlying the winning innovation available to the world at no cost or on concessional terms. At the extreme, such a requirement would likely discourage potential entrants from participating for fear that if they won, they would lose control over their innovations. If the winning innovation were developed in any part using federal funds, the Bayh-Dole Act would apply, allowing the contestant to take title to and license or sell the intellectual property developed in pursuit of the prize, subject to federal government rights to practice the invention for government purposes without royalty and ability to "march in" and take control of the invention in extraordinary circumstances. If no federal funds were used in making the winning innovation, the federal government should have no equity position from which to demand march-in rights to prizewinning intellectual property.

It is possible that an innovation proposed as a prizewinner would

[12]NSF's formal reconsideration procedure, described in the Grant Policy Manual, for NSF decisions not to make a grant award is not appropriate for the prize program in the committee's view because the ultimate authority to decide such a case is a level below the director.

make use of components or methods that had been patented or copyrighted by parties other than the contestant. To guard against possible infringement a team that is under consideration for the award of a prize should be required to make a good-faith effort to identify such intellectual property and should be required to acknowledge that it would need licenses from its owners to put the winning innovation into commercial or research use.

Contest-specific Rules

In addition to the general administrative rules applicable to all innovation inducement contests discussed in the preceding section, specific rules would be needed for each individual contest. These rules would define the form of each prize, the criteria for winning the prize, the method by which winning would be determined, and when appropriate the criteria that a potential contestant would need to demonstrate its competence to pursue a prize.

In the committee's view crafting these prize-specific rules is likely to be a challenging and different task for each contest. The experience of other organizations, including DARPA, NASA, and the X-Prize Foundation, has been that writing contest rules requires extensive consultation with experts, affected parties, and potential contestants to ensure that the stated prize goals are clear, understandable, and unambiguous; that the proposed prize goals represent important societal needs and opportunities; that the contest objectives embody a significant yet achievable advance over the current state of the art; and that it will be possible to determine in a relatively unambiguous way whether a particular innovation should qualify as the winner.

Rules are also needed to specify the form of any notification or application required from contestants who believe they have won a contest, the nature of the information required to be submitted in this notice or application, and the requirements for witnessing or other validation of a team's claim that it has achieved the contest objective.

Defining the Contest Objectives

It became apparent to the committee during its deliberations that defining the precise form of the objective of a contest is a challenging task. It is one thing to articulate the thought that one or more goals of national significance may make an interesting prize topic. It is another thing to express that thought in the form of the accomplishment of an objective that would help reach the national goal in a way that would be new, different, and a substantial advance over what can presently be accomplished

at about the same time in the absence of a contest. That is, the task of translating the broad societal goal of a contest into a concrete proximate objective that can be measured can be demanding.[13]

The task is somewhat different when the innovation being sought is relatively fundamental in character, reflecting an advance in science or basic technology, versus when the innovation represents the commercially successful application of a new idea, method, or technology. For more technically focused contests, achieving a defined technical objective may suffice as an indicator of success. The private marketplace (or, sometimes, government procurement) usually determines whether a more applied innovation is successful. Success of such innovations is measured by sales, profitability, market share, consumer acceptance, winning a competitive procurement, and the like. For NSF innovation inducement contests that seek to encourage innovations that address important societal problems, however, the committee believes that nonmarket objectives, rather than marketplace acceptance, should be used to judge success.

Accomplishing a well-chosen, well-defined nonmarket objective should in some sense stand as a surrogate for market success; moreover, it can contribute to such success. The U.S. innovation system as a whole, at least in comparison with other national systems of innovation, is adept at picking up good technical ideas and carrying them on to the marketplace. An NSF inducement prize program can play a valuable role in this process not only by identifying sound technical solutions to problems but also by conferring a "halo effect" that may help winners attract further investment.

In every case the challenge is to determine what should be set as the concrete objective of a prize contest. Suppose, for example, that NSF were to consider offering a prize with the broad goal of encouraging innovation in nanotechnology. There is widespread agreement that nanotech-

[13]The Ansari X-Prize, for example, used in lieu of a market test the objective requirements that a craft could reach suborbital heights (100 km) with a human cargo twice in a two-week period and return safely, with a maximum of 10 percent of craft weight to be replaced during the two-week interval. These contest conditions were apparently intended by the prize organizers to be a reasonable surrogate for what could not yet be achieved or evaluated—development of a successful commercial space tourism business.

In the government market arena, DARPA's Grand Challenge prize for autonomous off-road vehicles established a series of contest objectives based on discussions with potential customers for such vehicles in the military services. Winning required completion of a 132-mile course through rugged desert countryside within 10 hours, as well as successful completion of a series of preliminary qualification tests.

Devising an objective for each contest that can serve in place of actual market success appears to be the most challenging intellectual aspect of contest design.

nology offers great promise for innovative applications in many fields, including medicine, high-strength materials, electronic devices, telecommunications, quantum devices, coatings, cosmetics, and so on. In light of this great promise, for what specific achievement should an inducement prize be offered, that is, what should be the contest objective? The contest objective could be a new fundamental scientific capability that could be widely applied in many domains of nanotechnology, or the objective could be demonstration of a flagship application thought to offer great promise but also great technical challenge. The committee suggests that it would be essential to confer with scientists and engineers active in the field of nanotechnology and to elicit from them desirable objectives for innovations that, if realized, could substantially advance nanotechnology applications. In addition to discussions with scientists and engineers, NSF may find it useful to examine existing technology road maps in which expert communities have identified the most important technical problems to be solved to enable advances in their fields.[14]

For more ambitious contests more complex judgments will have to be made about whether an innovation is likely in the longer term to achieve market success, for example, in new sources of energy. There are many options for designing a contest in this field. Such a contest could be framed, for example, by offering a prize for a dramatic innovation in energy supply generally, for an innovation in carbon-neutral energy systems, or for an innovative catalyst for conversion of biomass to usable transportation fuels. Each of these operates at different levels within the sociotechnical energy system and each poses its own dramatic yet different challenges. Framing an energy supply contest around broader definitions of the societal goal may lead to more significant developments, yet may also make it challenging to define contest objectives that are sensible and for which winning can be objectively assessed.

Conversely, framing an energy supply contest around a narrow goal may yield interesting innovations within the scope of the contest, yet fail to stimulate innovations that might be of greater overall importance but that would fall outside the contest objective. Furthermore, to help achieve

[14]These road maps are exemplified by the International Technology Roadmap for Semiconductors, 2005 edition, International Roadmap Committee, online at *http://www.itrs.net/Links/2005ITRS/Home2005.htm*. A comprehensive history and review of technology road maps in general, including the various semiconductor road maps, can be found in. Schaller, Robert R. "Technological Innovation in the Semiconductor Industry: A Case Study of the International Technology Roadmap for Semiconductors." Ph.D. Dissertation, Fairfax, Va., George Mason University, April 2004, full text on the web at *http://www.xecu.net/schaller/schaller_dissertation_2004.pdf.*

goals of such broad societal significance and great technical challenge, it may be useful to structure the contest to include a series of prizes for achieving intermediate objectives, as well as a grand prize to recognize a substantial capstone innovation that fulfills a more ambitious objective. Defining the contest rules for this kind of complex area will take a substantial commitment of talented staff and advisers, resources, and time by NSF. The committee recommends the broadest possible outreach by NSF to the technical, professional, public interest, and industrial communities in defining prize and contest goals and objectives.

Form of the Prize

Most innovation inducement prizes feature a single cash award to the winner. The winner may also enjoy substantial good will and publicity. NSF may wish to follow that practice. We can imagine other types of awards, such as a cash prize provided over a period of several years, using lottery payouts as a model. Another type of prize would be a guarantee that the government would procure a certain number or value of products or services based on the prizewinning innovation. Yet another form of prize could be a guaranteed research grant or contract to the winner or the winner's institution in support of the winning team's continuing research. An interesting suggestion is that NSF could offer as part of a prize package a tour of the U.S. facilities it manages in Antarctica, a rare opportunity that could stimulate a great deal of interest on the part of both contestants and the general public. Of course, any variation from a single cash award could result in a more complicated process for administering the prizes, which may not be worth its cost to NSF or to the winner.

Demonstrating Qualifications to Compete

For some contests NSF could require that potential participating teams demonstrate their competence through a preliminary contest or demonstration. This approach has been used by DARPA in its autonomous vehicle prize competitions. DARPA's motivation was that because the comparison of different teams' accomplishments entailed use of expensive military resources, it was appropriate to ensure that participants had a reasonable chance of performing competitively. In the NSF case this may be necessary only if part of the contest similarly involved access to and use of sophisticated federally owned measurement or testing equipment or facilities, or if there are aspects of the prize that would require administrative resources that increase significantly with the number of contestants. Such a procedure amounts to a preliminary contest and would re-

quire careful attention to criteria for being able to move forward, just as for the main contest event.

Method for Determining Contest Winners

For first-past-the-post contests structured around accomplishment of objectively and quantitatively measurable objectives, the method of determining winners would be relatively straightforward. Teams that believe they have met the contest objective would submit a claim to that effect to NSF or its implementing contractor along with supporting evidence. NSF would use its own staff to confirm the claim or would contract with a separate measurement organization to check the claims of the applicants.

For best-in-class prizes to be awarded on the basis of performance criteria involving a degree of expert judgment, NSF or its contractor would convene expert panels to judge the representations of competing teams. Verification by a separate panel of judges may be desirable to ensure credibility of the decision.

AWARDING INNOVATION INDUCEMENT PRIZES

One of the purposes of an innovation inducement prize program is to raise public awareness of the importance of innovation to the economy and society and to generate excitement about the enterprise. Prizes should be awarded in a manner consistent with this purpose. This suggests that officials at NSF, the White House, and the Congress be engaged in public award ceremonies with a level of effort expended to make the award ceremony, as well as demonstration of the innovation in cases in which this would be effective, a significant newsworthy event.

Larger awards will entail relatively large sums of money to be awarded to teams that develop innovations of great national significance. Public and official recognition of these prize awards should be on a par with that accorded the annual awards of the Nobel Prizes in the sciences or to the annual award by the President of the National Medals of Science and of Technology. In such cases the award ceremony could be a commercially sponsored event on national television, perhaps packaged as a national celebration of innovation.

EVALUATING THE INNOVATION INDUCEMENT PRIZE PROGRAM

To ensure that NSF garners the greatest possible information and wisdom from its experiences with the program, it should engage one or more

external evaluation teams in tracking the development and implementation of the program from its earliest stages. The program should include a vigorous formative evaluation, which should be carried out competitively by teams from academia or appropriate nonprofit or for-profit evaluation firms. The evaluation teams should be managed by the OIP and report directly to the director of the NSF and to the National Science Board.

In the program's early years it would be too soon to attempt a summative evaluation, that is, to evaluate whether the program accomplished its ultimate goals or to assess its contribution to the nation. Instead, a formative evaluation strategy would focus on measures that would provide insight into whether the program's anticipated short-term impacts were being achieved on a continuing basis, and which features of the prize contests are more or less successful.

Among the relevant indicators of positive near-term program impact could be

- whether the contests attract large numbers of contestants;
- whether those contestants are a more diverse group than the traditional NSF constituency;
- whether, to what extent, and from what sources private funds are forthcoming to support the research activities of contestants or even to augment the prize purses;
- whether prize rules and processes functioned well;
- whether the contestants make related innovations that are successfully spun off from the main prizeseeking activity;
- and whether the program significantly advances innovation in the area of the prize topics.

Assessments could also be made of whether public awareness of and interest in innovation or the impacts of a specific prize are enhanced by the prize program, and whether NSF's public image is affected by its sponsorship of the program. Among the relevant program design variables to be examined are

- the duration of the contest, the size of the prize purse,
- whether the contests are first-past-the post or best-in-class,
- whether a contest is administered by NSF or by a contractor,
- and whether a contest includes prizes for achievement of intermediate objectives.

Evaluation teams could also examine whether NSF's administration of the program is effective as measured by accomplishment of NSF's own stated goals for the program.

3

Selecting Prize Topics and Implementing Early Prize Contests

In this section we offer more detailed suggestions for processes and criteria that the National Science Foundation (NSF) may wish to use to identify and select prize topics and to design the contests to go with them.

PROCESSES FOR IDENTIFYING PRIZE TOPICS

Elsewhere in this report we discuss the importance of NSF's reaching out to the larger scientific, technical, and other communities for ideas about suitable prize topics. We do so because we are convinced that conceiving of promising innovation inducement prizes is an exercise for which few people have experience. There are no experts on this today, in contrast to the large numbers of people who are experts on the identification of research opportunities, the design of financial incentives for private R&D spending, or the patent system. Topics that make good prize candidates may not be framed in the same terms as, say, R&D topics, and this suggests outreach well beyond the traditional sources of external advice for NSF and well beyond the capacity of an ad hoc committee formed for its familiarity with many fields in NSF's broad portfolio rather than depth of expertise in any single field or a few fields.

Our committee was mindful too of its short life and limited meeting time and of the recent experience of other agencies' prize programs. DARPA's selection of autonomous vehicle technology followed a series of studies but was also guided by a congressional directive in the FY 2001 National Defense Authorization Act to have unmanned ground combat

vehicles constitute one-third of the Armed Forces' fleet by 2015.[1] NASA's selection of topics for its Centennial Challenges followed an internal process of idea generation and a two-day Washington, D.C., workshop attended by over 200 representatives from aerospace and nonaerospace companies, universities, and other government agencies, divided into six brainstorming sessions. Approximately 30 promising ideas were then considered in detail in subsequent rules definition sessions.[2]

The committee decided to discuss a number of possible prize topic areas for NSF but not with an eye toward recommending them. Rather, we discussed them as means of exploring and better understanding how prize contests could be structured around them. Obviously, these discussions were not exhaustive. Here are a few of those topics, along with our thoughts on what could be done to transform them into goals that would drive innovation inducement prize contests. It should be noted that a number of plausible initial suggestions fell into the domains of defense, space, and medicine, but we considered these unlikely candidates for NSF, at least in the early stages of its program.

Fast, sensitive, and cost-effective chemical sensors for pollutants. The goal of a contest in this area would be to stimulate development of an array of chemical sensing devices that could be used to monitor a range of indoor and outdoor environments for the presence of a large number of chemical substances as pollutants or as chemical weapons. Low cost and high reliability are hallmarks of what is hoped for. This suggests that the contest objective would be multidimensional, including necessary levels of sensitivity and specificity, lifetime in use, compatibility with integrated monitoring systems, responsiveness to a target set of chemical species, and some measure of the anticipated costs of manufacture, integration, and application of multisensor devices.

Nano self-assembly. The promise of nanotechnology is predicated in part on achieving generalized methods of producing useful materials and devices at nanoscale by employing self-assembly methods in solid state, in solution, or perhaps in living systems. Many specific approaches to molecular self-assembly have been demonstrated in laboratory experiments in recent years. There is no generalized theory or algorithm that enables the material or device designer to depend on self-assembly methods with confidence, but such a generalized approach could be both feasible and valuable.

---

[1]Defense Advanced Research Projects Agency. *Grand Challenge 2004: Final Report.* Arlington, Va.: July 30, 2004.

[2]National Aeronautics and Space Administration. *2004 Centennial Challenges Workshop Report.* Washington, D.C.: October 26, 2004.

Green chemistry. In recent years industry, consumers, and environmentalists have all embraced the concept of green chemistry as a promising strategy for avoiding or substantially reducing the creation of risks to human health and the environment by choosing alternative chemicals or by redesigning processes to use or create lesser amounts of harmful environmental releases or waste. Because many of the most common organic chemicals are also used in myriad applications, a strategy of one-for-one substitution of less harmful for more harmful substances is not always feasible or successful. An inducement prize contest or contests could be organized around discovery of new products and processes to allow for substitution of one or more widely used, highly hazardous chemicals in commerce.

Low-carbon energy technologies. Reducing greenhouse gases, and energy-related carbon dioxide emissions in particular, is a crucial national and international goal. Significant reductions in carbon dioxide require large-scale changes in the technologies used to produce energy, the products and processes that consume energy, and the means available to store energy. Substantial innovation in low-carbon energy supply technologies and in the efficiency of energy-using technologies holds promise for achieving such carbon reductions at significantly reduced cost. Given the widespread application of energy technologies and the broad reach of energy systems, there are many possibilities for employing innovation inducement prizes to overcome technical and scientific challenges in low-carbon energy supply, demand, and storage technologies, including biofuels, solar energy, advanced wind energy, fuel cells, advanced lighting, nuclear fission and fusion, hydrogen storage, and advanced batteries. At the same time, because energy production and utilization systems are complex systems with many interdependent parts, it will be a considerable challenge to design successful prizes that contribute to replacing significant amounts of the high-carbon energy currently used in industry, transportation, and residences.

Catalysts for converting cellulosic biomass into liquid fuels. Recent advances in enzymatic catalysis have opened new possibilities for converting a wide variety of cellulosic biomaterials into useful liquid fuels. Further improvements in the performance and reduction in the cost of process that use catalysts is a top priority for the energy sectors in government and industry as a means for helping curb the use of fossil fuels. Current catalytic processes usually are not cost efficient for production of large quantities of liquid fuels. A prize could be given for discovery or development of one or more new catalysts that have the desirable technical properties, promise to be manufacturable at low cost, and enable production of high volumes of fuels. Experts in the field should be able to agree on the technical properties relatively directly. Additional study and

analysis would be needed to develop a suitable surrogate measure for economic performance to serve as the contest objective.

Advances in computing architecture and performance. Contemporary state-of-the-art digital computers (i.e., supercomputers) consume much more energy in computation than would be predicted by consideration of thermodynamic limits, which leads to compromises in design and performance including high prices, excessive heat generation, and low utilization of system capabilities. Prizes could be offered for specified improvements in computing performance on certain types of problems, including the possibility of using quantum computing approaches to address certain performance limits. Nevertheless, the specific objective and design of a prize would need to take into account both the current market-driven investment in many technical avenues and the technology insertion problem with any radical breakthrough.

Learning technology/software for teaching science and mathematics at the K-12 levels. The nation faces a widely acknowledged crisis in preparing sufficient numbers of young people for careers and for citizenship roles that require an understanding of science and mathematics. There is reason to believe that learning technologies, including but not limited to software of many kinds, can contribute to more effective learning of these concepts at the K-12 levels. Innovations in such technologies could be encouraged through a prize that would reward the developers of such technologies that demonstrated a record of success in improving various measures of math and science learning in various educational settings, as compared with control groups taught by more established means.

We have only scratched the surface of possible prize topics, and we most assuredly have not developed any of these into plans for contests to be set in the immediate future. We hope, however, that this brief discussion will assist the NSF in considering topics for its first round of prizes.

In the early days of establishing an innovation inducement prize program, NSF needs to act fairly quickly to select, design, and announce a small number of first-round contests on somewhat limited specialized topics on which there may already be a strong consensus among technical and business leaders about the most important barriers to further development. We believe that these can be identified by canvassing specialists in a few fields, beginning with NSF's own program managers and incorporating suggestions from scientific and technical societies, federal laboratories, industrial research managers and planners, and others familiar with the state of the art of relevant technologies and bodies of practice. Where systematic studies have been done to identify opportunities in important fields, they should be examined for potential prize topics. As did NASA, we believe it would be helpful for NSF to hold a public workshop to vet and refine a number of topics before NSF's final selection. NSF offi-

cials should consult NASA about the most effective and efficient organization of such a workshop.

The selection process should proceed together with other tasks that need to be addressed at the outset, including

- Establishing and staffing the Office of Innovation Prizes (OIP) or its equivalent;
- Initiating work on the prize program administrative rules;
- Convening a formal advisory committee to the program;
- Drafting a prize program announcement, including registration procedures and forms; and
- Appointing working groups of NSF staff, augmented by contractors or consultants, as needed, to develop each of the three to five prize contest statements, including the contest-specific rules described above.

We believe that it is a reasonable objective to announce the first round of contests in the latter part of 2007.

For more ambitious prizes more time and resources will be needed to identify prize topics. The challenge is to identify goals that are significant for society, scientifically and technically challenging, and achievable in a reasonable period of time through sustained intellectual and creative effort. While it is straightforward to identify broad areas of great societal need, it is another matter altogether, the limited experience shows, to extract from those statements of need a coherently designed prize goal and related contest objectives. A comprehensive systems approach to this challenge could be helpful. The purpose of such an analysis would be to identify and describe the principal elements and connections of a complex system, such as a nuclear power production facility, a hospital, a major city educational system, or a quantum computer, for the purpose of locating the critical innovations needed to enable major improvements in such systems. These innovation goals would then become candidates for large-scale innovation inducement prize contests. This sort of analysis could be carried out by NSF staff, by expert panels convened by NSF or a contractor, or by experts in strategic planning and analysis. They should be published and circulated for comment to diverse constituencies with an interest in the general topic for information and validation. This work will be in anticipation of announcing one or major prize contests in the latter part of 2008.

CRITERIA FOR SELECTION OF PRIZE TOPICS

Here we summarize under several categories the large number of criteria that could be employed to decide which set of candidate topics should be the focus of an NSF inducement prize program.

Criteria Related to Government Encouragement of Innovation

As for any other mode of government support of or incentives for innovation, inducement prizes should be offered in cases that comport with common understanding of the rationales for government involvement in the innovation process, namely, that the development and application of the hoped-for innovation meets the following criteria:

- The contest goal is widely judged to be worth pursuing and is in fact among the most important challenges facing the nation.
- If a prizewinning innovation is developed and put into practice, it will offer substantial practical benefit not only to its producers and users but also to the nation as a whole.
- Pursuit of the innovation should be perceived as a high-risk but high-reward activity.
- Without government intervention the market is unlikely to produce the innovation in a timely or effective manner, that is, the usual arguments from market failure for an affirmative federal involvement in the innovation process should apply to prize programs just as they do to other programs and policies intended to encourage innovation.

Criteria Related to the Use of the Inducement Prize Mechanism

The committee believes that offering inducement prizes is more relevant for pursuing some national goals than for others. To be appropriate as the target of an inducement prize, either in place of a grant program or as a supplement to it, the contest should have most of the following characteristics:

- The prize goal should represent an ambitious effort, well beyond the current state of the art.
- It is expected that the contest objective can be achieved within a reasonable time frame for a prize program; on the order of 2 to 10 years.
- It will be possible to determine in a relatively objective manner whether a particular contestant's innovation has in fact achieved the contest objective.

- It will be feasible to define a plausible contest objective that is a suitable surrogate for the test of innovative success that is usually applied in the marketplace.
- The contest will encourage a wide range of types of contestants, including those not ordinarily active in the research grant and contract world, to participate.
- The goal is unlikely to be achieved, at least not in a reasonable time, using traditional grant and contract modes of encouragement alone.

Criteria Related to Broad Outreach and Engagement

It is widely agreed that inducement prizes are especially useful in seeking to broaden the range and scope of entities that compete for federal support of innovation. This suggests additional criteria for selection of candidate topics around which to structure prize offerings:

- The goal should be reasonably meaningful to the general public and understandable by a wide range of potential contestants.
- The methods and tools required to compete effectively should be available to a reasonably large number and wide range of potential contestants.
- The process of competing for the prize should encourage formation of new social networks among individuals, firms, government laboratories, financial institutions, and others, who can contribute to future innovative activities.

Criteria Related to Political and Social Constraints

A variety of political and societal constraints should be considered in selecting prize topics, including:

- Achieving contest objectives should not require use of classified information or technologies nor should it result in inadvertent creation of same.
- Pursuing the prize should not pose unreasonably large risks to contestants, NSF, or the larger society.

Criteria Related to NSF's Involvement

- The prize goals and associated objectives should draw on the technological and scientific strengths of the NSF, its staff, and its advisory apparatus.

- Early prize topics should be selected with an eye toward their likely contribution to building NSF's capabilities for mounting longer prize contests.
- When a contest is being considered that would help fulfill the missions of other federal agencies, those agencies should be invited to participate in administering and funding the prize contest.
- Contests should encourage entry by experts and practitioners in a variety of disciplines and fields.

CONCLUSION

The challenge to establish a program of innovation inducement prizes presents the NSF with an unusual opportunity to try a number of different approaches and designs for prizes, both to pursue the broad objective of stimulating innovation throughout a wide range of U.S. institutions and to develop a database of experience with such prizes that can inform policy makers and agency officials about their uses and limitations.

The committee believes that an ambitious, albeit in its early stages experimental, program of innovation inducement prize contests, carried out in close association with the academic community, scientific and technical societies, industry organizations, venture capitalists, and others, will prove to be a sound investment in strengthening the infrastructure for innovation in the United States.

Appendixes

Appendix A

Comparison of Recent Prize Competitions

TABLE A-1 Comparison of Recent Prize Competitions

	NASA Centennial Challenges	DARPA Grand Challenge 2004, 2005, 2007	NAE Grainger Challenge	Ansari X-Prize
Target	Technology for space exploration	Autonomous vehicles	Arsenic removal from water supply in LDCs	Private space travel
Type	Variety of annual and one-time challenges (generally best in class)	Annual or biannual races	One-time prize (best in class)	One-time prize (best in class)
Prize purse	$200,000-$2.5 million (prize amounts to increase over time)	$1 million per race	1st $1 million 2nd $200, 000 3rd $100, 000	$10 million
Federal employee eligibility	No	Yes (using free time)	Yes (using free time)	N/A

TABLE A-1 Continued

	NASA Centennial Challenges	DARPA Grand Challenge 2004, 2005, 2007	NAE Grainger Challenge	Ansari X-Prize
Foreign nationality eligibility	No	Yes (except team leaders must be U.S. citizens)	No (U.S. citizen at U.S. institution or resident in the U.S. at the time of award)	Yes
Participants required to register	Yes	Yes	Yes	Yes
Screening of participants	Yes (for safety where applicable)	Yes	Yes (15 entries cleared for physical testing)	Yes (primarily for safety and seriousness)
IP rights	Contestant has title (NASA retains option for nonexclusive license)	Contestant has title (DARPA retains nonexclusive license)	Contestant has title (NAE obtains license in order to test)	Contestant has title
Media rights	Requires that contestants relinquish some media rights	Not in the rules	Not in the rules	Contestants relinquish some media rights
Intermediate awards	No	Yes	No	No
Funding source	NASA appropriations ($500,000 from private sources for $2.5 million Lunar Lander challenge)	DARPA appropriations	Nonprofit foundation	Insurance policy purchased with private funding
Administration	NGOs without compensation under Space Act agreements	DARPA	NAE	X-Prize Foundation
Future prizes	Planetary Unmanned Vehicle Challenge	2007 Urban Challenge; prize authority extended to other parts of DOD	Unknown	X-Prize Cup; Auto X; Genomics X

Appendix B

Committee and Staff Biographies

MARK B. MYERS (*Chair*) retired from the Xerox Corporation at the beginning of 2000 after a 36-year career in its research and development organizations. He was the senior vice president in charge of corporate research, advanced development, systems architecture, and corporate engineering from 1992 to 2000. His responsibilities included the corporate research centers: PARC in Palo Alto, California; Webster Center for Research and Technology near Rochester, New York; Xerox Research Centre of Canada, Mississauga, Ontario; and the Xerox Research Centre of Europe in Cambridge, U.K., and Grenoble, France. Dr. Myers served on the National Academies Science, Technology, and Economic Policy Board from 1995 to 2005 and cochaired the board's study of the patent system, resulting in the report *A Patent System for the 21st Century.* He is chairman of the Board of Trustees of Earlham College and has held visiting faculty positions at the Wharton School of Business, University of Rochester, and Stanford University. He holds a bachelor's degree from Earlham College and a doctorate from Pennsylvania State University.

ERICH BLOCH is a principal of the Washington Advisory Group, a distinguished fellow at the Council on Competitiveness and a former NSF director. He is the only past director with an industrial background. As an IBM electrical engineer early in his career, Mr. Bloch was a key figure responsible for IBM's STRETCH Computer Systems Engineering project and the development of the IBM 360. For his role in that system he was awarded the National Medal of Technology in 1985 and the IEEE Founders Medal. In his six-year term (1984-1990) as NSF director, Mr.

Bloch built national support for advances in high-performance computing and networking and led in transitioning the NSFNET to the commercialized Internet. He also established NSF's Computer and Information Science and Engineering Directorate, the Engineering Research Centers program, and the Science and Technology Centers program. Mr. Bloch is a member of the U.S. National Academy of Engineering, the Swedish Academy of Engineering Sciences, a fellow of IEEE, and a foreign member of the Engineering Academy of Japan. From 1992 to 1996 Mr. Bloch was chairman of the National Research Council's Japan Affairs Committee. He received his education in electrical engineering at the Federal Polytechnic Institute of Zurich and earned a bachelor of science degree in electrical engineering from the University of Buffalo in 1952.

STUART I. FELDMAN joined IBM in 1995 and is now vice president, computer science in IBM Research. He is responsible for driving the firm's long-term exploratory worldwide science strategy in computer science and related fields, such as mathematics, management sciences, and social sciences. Dr. Feldman leads programs for adventurous research and university collaborations, represents computer science research at senior management levels in IBM, and is the technical leader of the Research Division's solution engineering initiative. Earlier positions at IBM included vice president for on demand business transformation strategy in IBM Research, vice president for Internet technology and director of IBM's Institute for Advance Commerce. Dr. Feldman did his academic work (A.B., Princeton, and Ph.D., MIT) in astrophysics and mathematics. He is a fellow of the IEEF and fellow and president of ACM, from which he received the Software System Award in 2003. In 2005 he received the Academy of Management Distinguished Executive Award. Before Joining IBM he was a computer science researcher at Bell Labs and a research manager at Bellcore. Dr. Feldman has taught e-commerce courses at Yale School of Management and is a consulting professor of information technology at Carnegie Mellon West.

MERTON C. FLEMINGS is professor of materials science and engineering, and director of the Lemelson-MIT program, which honors inventors and encourages inventiveness among young people. He received his S.B. degree from MIT in the Department of Metallurgy in 1951 and his S.M. and Sc.D. degrees in 1952 and 1954, respectively. He has been a professor at MIT since 1956 and was head of the Department of Materials Science and Engineering from 1982 to 1995. Dr. Flemings was the founding director of the MIT Materials Processing Center. His research and teaching focus on engineering fundamentals of materials processing and on innovation of materials processing operations. He is a member of the National

Academy of Engineering and the American Academy of Arts and Sciences. He has worked closely with industry and on industrial problems throughout his professional career and currently serves on a number of corporate and technical advisory boards.

CLAIRE GMACHL is an associate professor of electrical engineering at Princeton University and the director of the newly formed NSF Engineering Research Center on Mid-InfraRed Technologies for Health and the Environment (MIRTHE). Her research group is working on the development of new quantum devices, especially lasers, and their optimization for systems applications ranging from sensors to optical communications. Before joining the Princeton faculty, she worked at Bell Laboratories, Lucent Technologies. She is a 2005 MacArthur Fellow and was named one of *Popular Science*'s "Brilliant 10" young scientists in 2004. In 1996 she received the Solid State Physics Award from the Austrian Physical Society and the Christian Doppler Award. She is a member of the Austrian Physical Society, the Optical Society of America, the American Association for the Advancement of Science, and the Institute of Electrical and Electronics Engineers, and has participated in the NAE's Frontiers of Engineering program. Dr. Gmachl earned her Ph.D. in electrical engineering from the Technical University of Vienna, Austria.

THOMAS A. KALIL is the special assistant to the chancellor for science and technology at the University of California, Berkeley, where he is responsible for developing major new multidisciplinary research and education initiatives at the intersection of information technology, nanotechnology, microsystems, and biology. He is also a senior fellow with the Center for American Progress. Previously, Mr. Kalil served as the deputy assistant to President Clinton for technology and economic policy, and the deputy director of the White House National Economic Council. He was the NEC's "point person" on a wide range of technology and telecommunications issues, such as the liberalization of Cold War export controls, the allocation of spectrum for new wireless services, and investments in upgrading America's high-tech workforce. He led a number of White House technology initiatives, such as the National Nanotechnology Initiative, the Next Generation Internet, and increasing funding for long-term information technology research. Prior to joining the White House, Mr. Kalil was a trade specialist at the Washington offices of Dewey Ballantine, where he represented the Semiconductor Industry Association on U.S.-Japan trade issues and technology policy. He also served as the principal staffer to Dr. Gordon E. Moore in his capacity as chair of the SIA Technology Committee. Mr. Kalil received a B.A. in political science and

international economics from the University of Wisconsin-Madison and completed graduate work at the Fletcher School of Law and Diplomacy.

DAVIS MASTEN is a principal at Cheskin Associates, a strategic consultancy in marketing and design research and innovation. His clients for projects in retail, packaging, interactive environments, corporate positioning, branding, and industrial design range from Pepsi and Hershey Foods to Microsoft and Hewlett Packard. Holding degrees in business and psychology, Mr. Masten joined Cheskin Associates Inc. in 1975, working closely with founder and market research pioneer, Louis Cheskin. Mr. Masten is a member of the National Academies' Presidents' Circle and assumed its chairmanship in 2007.

KAREN E. NELSON was born in Jamaica and migrated to the United States, where she completed a Ph.D. in microbiology at Cornell University. For the past 10 years she has worked at the Institute for Genomic Research in Rockville, Maryland, where she has been involved in the whole genome sequencing and analysis of numerous microbial species including *Thermotoga maritima, Campylobacter jejuni, Listeria monocytogenes* and *Salinibacter ruber.* In addition, she has led a number of metagenomics projects to analyze the human oral cavity, gastrointestinal tract, and the rumen. Dr. Nelson has been involved in many outreach projects with minority institutions and is currently employed at Howard University in Washington, D.C. She is also editor in chief of *Microbial Ecology*. Dr. Nelson was one of the microbiologists featured in a TV series called *Intimate Strangers: Unseen Life on Earth*, which appeared on PBS in 1999.

RICHARD G. NEWELL is a senior fellow at Resources for the Future, an independent nonprofit and nonpartisan research institution. Dr. Newell's research and outreach efforts center on the economics of markets and policies for energy and related technologies, particularly the cost and effectiveness of alternatives for reducing greenhouse gas emissions and achieving other environmental and energy goals. Economic analysis of market-based policies, technology policies, and the influence of markets and policy on technology innovation and adoption are important themes in his work. During 2005-2006 he served as senior economist for energy and environment at the President's Council of Economic Advisers. He has served as an independent expert advisor, reviewer, and consultant for many public and private institutions. Currently he is an advisor to the National Commission on Energy Policy and a member of the National Research Council's Committee on Energy R&D and the Advisory Board of the Automotive X-Prize and the editorial board of the journal *Energy Economics*. He received his Ph.D. from Harvard University,

master's degree from Princeton's Woodrow Wilson School of Pubic and International Affairs, and undergraduate degrees in engineering and philosophy from Rutgers University.

PETER M. RENTZEPIS was born in Kalamata, Greece, and was educated at Cambridge University, England, where he received his Ph.D. He was on the research staff and then became head of chemistry at Bell Laboratories. He subsequently was appointed Presidential Chair and professor of chemistry and electrical and computer engineering at the University of California, Irvine, where he serves currently. Professor Rentzepis is a pioneer of ultrafast, picosecond, and subpicosecond methods for the study of ultrafast phenomena. He is the first scientist to measure and use these pulses for scientific research and the study of processes in chemistry, physics, and biology occurring in the 10-12 seconds (trillionth of a second) or less. He has received over 25 national and international awards for his research, including the Langmuir Award in Chemical Physics, Tolman Medal in Chemistry, Cressy Morrison Award in Natural Sciences, Peter Debye Award in Physical Chemistry, and the ISCO Award for Biological Sciences. He is a member of the U.S. National Academy of Sciences and the Athenian Academy.

SUZANNE SCOTCHMER is professor of economics and public policy at the University of California, Berkeley; she has also taught at Harvard University. Her graduate degrees are in economics and statistics. She has held visiting appointments at the University of Auckland, University of Cergy-Pontoise (Paris), Tel Aviv University, University of Paris I (Sorbonne), Boalt School of Law, University of Toronto Law School, Yale University, Stanford University, and the New School of Economics, Moscow. She has published on intellectual property law, rules of evidence, tax enforcement, cooperative game theory, club theory, and evolutionary game theory. She has served on committees of the National Research Council and is currently a member of the Board on Science, Technology, and Economic Policy. The Department of Justice Antitrust Division has used Dr. Scotchmer as a consultant on antitrust matters, and she has been a scholar in residence at the U.S. Court of Appeals for the Federal Circuit.

MARGARET STEINBUGLER is manager of the Transportation Fuel Cell Systems program at UTC Fuel Cells. Her research interests are in the design of PEM fuel cell systems for high reliability, durability, operability, and low cost. She has published several papers in the areas of fuel cell systems and hydrogen studies and has been awarded several patents in fuel cell systems. She earned degrees in chemical and mechanical and aerospace engineering from Princeton University.

STAFF

STEPHEN A. MERRILL (*Study Director*) has been executive director of the National Academies' Board on Science, Technology, and Economic Policy (STEP) since its formation in 1991. He has directed several STEP Board projects in the areas of intellectual property, technical standards, taxation, human resources, and statistical as well as research and development policies. For his work on the report *A Patent System for the 21st Century* (2004) he was named one of the 50 most influential people worldwide in the intellectual property field by *Managing Intellectual Property* magazine and was awarded the National Academies' Distinguished Service Award in 2005. Prior to his appointment to the National Academies staff, Dr. Merrill was a fellow in international business at the Center for Strategic and International Studies and served on various congressional staffs, including that of the Senate Commerce, Science, and Transportation Committee, where he organized the first congressional hearings on international competition in the semiconductor and biotechnology industries. He holds degrees in political science from Yale (M.A., Ph.D.), Oxford (M. Phil.), and Columbia (B. A.) universities.

CHRISTOPHER T. HILL is professor of public policy and technology at George Mason University, where he also served for eight years as vice provost for research. He is a principal in the consulting firm, Technology Policy International, where he has advised Japanese government agencies. Dr. Hill has served as a senior staff member at RAND's Critical Technologies Institute, the Center for Policy Alternatives at MIT, and the National Academies, where he was executive director of the Manufacturing Forum. He was senior specialist in science and technology policy at the Congressional Research Service and was on the staff of the Office of Technology Assessment. During 2005-2006 he was a public policy scholar at the Woodrow Wilson International Center for Scholars, where he began work on a book on the foundations of U.S. technology policy.

PROCTOR REID is director of the Program Office of the National Academy of Engineering (NAE), which he joined as an NAE fellow in 1988. He has directed numerous projects on issues related to technology, trade, and economic growth. He was project director for the 1999 NAE report *Concerning Federally Sponsored Inducement Prizes in Engineering and Science* and currently is administering the 2007 Grainger (Foundation) Challenge Prize for the best means of removing arsenic from underground drinking water in developing countries. Dr. Reid received his Ph.D. in international relations from the Johns Hopkins University Paul Nitze School of Advanced International Studies.

BENJAMIN ROBERTS served with the National Academies' Board on Science, Technology, and Economic Policy as a Christine Mirzayan Science and Technology Policy fellow in the summer of 2006. He is a graduate of Carleton College and the University of Michigan School of Law. He was an attorney with the Hawaii Department of the Attorney General before returning to the Kennedy School of Government, Harvard University, where he is completing an M.P.P degree.

MAHENDRA SHUNMOOGAM received a B. Soc. Sc. in political science and governance from the University of Cape Town, South Africa. He pursued legal studies at the University of the Western Cape and worked for the premier of the Western Cape Province, in documentary filmmaking, and for the South African Treatment Action Campaign before coming to the United States. He joined the staff of the National Academies' Board on Science, Technology, and Economic Policy in June 2006.