BRIDGING THE GAP BETWEEN SCIENCE AND SOCIETY

The Relationship Between Policy and Research in National Laboratories, Universities, Government, and Industry

November 1–2, 2003
Rice University
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Hosted by:
Rice University Department of Physics and Astronomy
James A. Baker III Institute for Public Policy
Los Alamos National Laboratory
National Science Foundation

Organized by:
Rosina Bierbaum, University of Michigan
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INTRODUCTION

James Cohen and Rosina Bierbaum

On November 1–2, 2003, the James A. Baker III Institute for Public Policy along with Rice University's Department of Physics and Astronomy and Los Alamos National Laboratory convened a two-day workshop titled "Bridging the Gap between Science and Society: The Relationship between Policy and Research in National Laboratories, Universities, Government, and Industry." This unique event brought together more than 30 top scientists and policy experts to discuss critical issues of energy and related science and technology policy.

This manuscript was produced to capture the presentations and discussions that took place at this conference. The speakers and panelists were asked to present their views during the conference as well as assist with the editing of their specific sections of the finished manuscript. The manuscript is not a literal transcript of the conference and many of the introductory remarks were not captured, but we hope that the spirit and intent of all the talks are reflected here. In addition, the views expressed in these talks are those of the individuals and do not necessarily represent the view of the James A. Baker III Institute for Public Policy or the other sponsoring organizations.

Both the book and the conference are dedicated to Neal Lane. As you will read in the eloquently written foreword, Neal Lane is a "civic scientist" and has had a substantial impact in both physics and public policy. We felt it was appropriate to organize this conference on some important aspects of science policy to encourage other scientists to engage in policy activities and to inform the general public about the positive public impacts of science in our society. The talks and comments captured in this volume had a similar goal, to insure that science brings solutions to the world's problems.

In addition, we would like to acknowledge Amy Jaffe and Kirstin Matthews for their work organizing and producing the materials in the manuscript. Without their efforts, this book would not have seen fruition.

James Cohen is the Group Leader for the Theoretical Division of the Atomic and Optical Theory Group (T-4) at Los Alamos National Laboratory. Rosina Bierbaum is the Dean of Natural Resources and Environment at the University of Michigan.

NEAL LANE, CIVIC SCIENTIST AND MENTOR

Michael A. Morrison

> ***His scientific life broadened into a life of public service that caused him to put all his knowledge and skills to work for the improvement of society.***
>
> – Neal Lane, "Benjamin Franklin, Civic Scientist" (2003)

You are about to read a remarkable collection of essays. Each essay evolved from a talk its author presented during an intensive two-day conference held during November, 2003 at the James A. Baker III Institute for Public Policy on the campus of Rice University in Houston. The authors comprise a veritable Who's Who of leaders in the branches of the federal government that are responsible for the health of science and technology in America.

Several traits unite these essays. First, each essay addresses an urgent global problem. Here you will read about energy, the environment, nuclear security, the escalating scientific illiteracy of the public, and more. Second, each essay addresses issues at the turbulent interface between science and public policy. And third, each essay addresses a major concern of the remarkable man in whose honor this conference was held, Neal Lane.

The authors of these essays acknowledge, directly or indirectly, the contributions Neal made to public policy during his recent tenure in Washington: first, from October 1993 to August 1998, as Director of the National Science Foundation (NSF); then, from August 1998 to January 2001, as Assistant to the President for Science and Technology and Director of the White House Office of Science and Technology Policy.

I want to introduce you to Neal as I know him, to the Neal Lane these essays will not tell you about. Attendees at the Rice Conference got a glimpse of the "other" Neal Lane during a raucous post-dinner roast masterfully presented by Peet Hickman, a faculty member at Lehigh University. Like Peet, James Cohen and Lee Collins of the Los Alamos National Laboratory—the driving forces behind the conception and realization of this conference—were students of theoretical physics in Neal's graduate research group in the Rice Physics Department long before Neal left the academy for Washington. I, too, was one of the lucky few in that group.

Neal trained graduate students and postdoctoral researchers at Rice from 1966 to 1984. He had come to Rice, via a postdoctoral appointment at Queen's University, Belfast, after getting his doctorate in 1964 from the University of Oklahoma. A native of the state, Neal spent his undergraduate and graduate years at Oklahoma, where, among his many accomplishments, he wooed and won his wife and partner Joni—who did almost as much as Neal to help us students survive the rigors of graduate training. Raised by parents who loved learning, Neal seemed born with a hunger for knowledge, a passion for learning, and a knack for explaining what he knew to others. After discovering while an undergraduate that, as he puts it, his "experimental skills were wanting," Neal turned to theoretical physics and joined the research group of Prof. Chun Lin, who is now a faculty member at the University of Wisconsin. Luckily for Neal, his wife Joni also loved computing and helped with his research during his graduate, postdoctoral, and early faculty years. Armed with a solid background in physics and mathematics, a visionary commitment to education as necessary concomitant to research, and a talented and computationally literate wife, Neal entered the academy and set up the group of students I later joined.

In those early years Neal focused, as must all newly-minted university faculty, on honing his skills as a teacher and forging his career as a scientist. In courses that ranged from the canonical and vital "Physics for Poets" to the archetypical arcana of advanced graduate specialty classes, he rapidly earned a campus-wide reputation as a witty, caring, and demanding teacher. In his research on the theoretical physics of atoms and molecules, he earned an international reputation as a careful and insightful scientist. (On campus, Neal's reputation as a scientist included his knack for devising thesis problems that turned out to be vastly more difficult than they initially seemed.) From 1962 to 1994 Neal, his collaborators, and his students wrote 105 refereed research papers that were published in the premier journals of professional physics. These papers, which reported research on such topics as ion collisions in plasmas, the physics of liquid helium, and collisions of low-energy electrons with molecules present in planetary atmospheres, represent an important contribution to our ever-growing base of knowledge about the physical universe and to exigent technologies such as lasers and potential sources of energy based on nuclear fusion.

What was it like to work for Neal? It was really hard. I once overheard Neal reveal a bit more about himself than he may have intended. A student in his freshman course for non-physics majors asked him how she could do well on an upcoming exam. With a friendly smile and a twinkle in his eye, Neal said, "know everything and don't make any mistakes." That about sums up the experience of being Neal's graduate student.

Always kind, always encouraging, and almost supernaturally patient, Neal never talked down to his students. He never imposed rigid deadlines. Rather, he let us find our own way. He let us struggle and flounder, but in a supportive, intellectually safe environment where we could make mistakes, fix them, and thereby mature as scientists. Still, at some primal level each of us knew that substandard or sloppy work just would not do, that only our best would suffice. Rather than drive his students, Neal used his nascent political acumen—a talent he would later refine in no less formidable a forum than the United States Congress—to channel our drive, ambition, and energy to do what he (rightly) thought was best for us. So deft was he at this art that only much later, if ever, did we realize that we had been benevolently manipulated.

Directing graduate students may sound trivial compared to directing NSF, but directing graduate students is no easy task. It requires a long-term investment of time and energy, an empathetic sensitivity to the human psyche, and steadiness in the face of occasional eruptions of student angst. Try as we might, none of us could quite figure out how Neal did it so well. But we were not idiots; we noticed clues. Throughout his career, Neal's signature style has been calm, reasoned argument. (Only once did I hear him lose his temper, during a phone conversation with an obdurate Mazda dealer.) Rather than hector and yell, Neal uses his charm, insight into human nature, and political skills to build consensus. Rarely does Neal overtly criticize others; he genuinely respects their opinions, even if he suspects (or knows) them to be wrong. His well-honed style enabled Neal to shape a bunch of bright, ambitious, but intellectually unruly young men and women into professional scientists, just as it later facilitated his work in government.

In Washington, at NSF, Neal created programs to encourage, support, and reward the synergistic integration of teaching and research, making this one of the Foundation's strategic goals. He led major efforts to streamline the process of peer review whereby the Foundation decides which research proposals merit funding, and to plan and fund the construction of large research facilities including telescopes, particle accelerators and detectors, a gravitational-wave observatory, and research ships and aircraft. He accelerated NSF's efforts to do business electronically, and established NSF's first child-care center for employees. He convinced the President and Congress to rebuild the aging South Pole Research Station, and fought back an effort by some members of Congress to deemphasize the social sciences at NSF. As if that was not enough, he also supported interdisciplinary initiatives in areas ranging from information technology to plant genomics, from Arctic research to climate change, and beyond. He was steadfast in defense of basic research during a time when industrial competiveness and technology transfer were at the top of all political agendas.

Later, as Science Advisor to President Clinton and Director of the Office of Science and Technology Policy, Neal fought for substantial increases in funding of all fields of research—especially in the physical sciences and engineering, disciplines that had long been neglected in the federal budget process. President Clinton's FY2001 budget included an increase for NSF that was almost double the largest dollar increase the agency had every received. Neal was a key White House advocate for what became the National Nanotechnology Initiative, which has continued to garner political support and annual funding of about $1 billion. In the White House, Neal also had responsibility for a wide range of science and technology matters involving health, energy, security, the environment and climate change, food safety and biotechnology, the human genome project, information technology, cybersecurity, partnerships with industry, international cooperation in research, the space program, and many others. In addition to sitting with cabinet members and at the President's table of advisors, Neal greatly expanded the role of Science Advisor as spokesperson for science to the public. By channeling his passion for ideas, insight into public policy, and understanding of science through his witty, self-effacing style, Neal became a media-aware communicator whose speeches and op-ed pieces, in venues from Rotary clubs to newspapers such as USA Today, are as persuasive as they are popular.

Through his efforts in Washington, Neal came to embody the concept of the scientist as activist citizen. Those of us who worked for Neal at Rice, long before his tenure in government, knew that his concept of a contemporary scientist was broader and deeper than ours. During many a party at the Lanes' house, his late night conversations with students, most of whom were blissfully sated with their first good meal in months, often turned to our responsibilities to the society that, we hoped, would support our research. In subsequent years, he refined his ideas into the figure of the civic scientist.

Neal recently described the civic scientist in speeches and in an article about America's first science advisor to the President, Benjamin Franklin, whom he identifies as "the founding father of civic science." Neal defines the civic scientist as "a thoughtful and mainstream contributory member of society" who "uses his or her special scientific knowledge and skills to influence policy and inform the public." For him, the qualities that made Franklin the paradigmatic civic scientist were his wisdom, his ability to communicate science to politicians and the public, his ability to transform conflict into consensus, and his willingness to accept and act upon the scientist's larger responsibilities to a world urgently in need of clear thinking and rational, fact-based analysis. Neal's description of Franklin as exemplary civic scientist is all but autobiographical.

Now Neal and Joni are back at Rice, where he is the Malcolm Gillis University Professor, a faculty member in the Department of Physics and Astronomy, and a Senior Fellow of the James A. Baker III Institute for Public Policy. The Baker Institute is an ideal home for Neal. As Institute Director Edward Djerejian puts it, "Neal Lane symbolizes what the Baker Institute is about—a bridge between the world of ideas and action." Happily, Neal is again working with students. Rather than theoretical physics, his current work focuses on policy matters related to energy, space exploration, the environment, nanotechnology, biomedical research, international cooperation among scientists, science education in K–12 schools, and, as always, communicating science to the public. When not working at Rice or jetting around the country serving on boards and giving speeches at conferences and universities, Neal enjoys scuba diving and spending time with Joni and their children, Christy Saydjari and John Lane, and four grandchildren: Allia and Alex Saydjari, and Matthew and Jessica Lane.

Throughout his long and varied career, Neal has served a remarkable range of constituencies. In Washington—at the White House and, before that, at NSF—Neal did a great deal of good for a great many people: the American scientific community and the general public. Prior to his Washington years—as Provost at Rice and, before that, as Chancellor of the University of Colorado at Colorado Springs—Neal served a smaller constituency: faculty and staff whom he inspired to better serve their constituents, the students.

Earlier still, as a faculty member in the Rice Physics Department, Neal served a far smaller group. He directed five master's students: Amelia Day, Thomas Cook, J. Alan Haggard, James O'Connell, and Benjamin West; and twelve PhD students: myself, Kenneth Black, Lawrence Carlson, James Cohen, Lee Collins, Stephen Evans, A. Peet Hickman, Steven Preston, M. Sam Shaw, Russell Simpson, Walter Steets, and Jon Weisheit. He collaborated with eleven postdocs: Bill Archer, R. Dixon, Chizuko Dutta, Greg Hatton, Mineo Kimura, Anil Kumar, Nely Padial, Bidhan Saha, Karl Scheibner, Tom Winter, and Barbara Whitten.

Mustering his intellect, passion for knowledge, and understated but unyielding insistence that we meet the highest standards, Neal trained each of us, one at a time, molding the chaotic energies of our enthusiasms into the disciplined rigor of the theoretical physicist. Without him, we would not be who we are today, and we will be forever grateful. Years later, in Washington, Neal focused those qualities on societal questions by leading visionary programs and by representing science to both the nation's leaders and to the general public. From Rice to the White House, Neal has shown what it means to be a civic scientist. Ben Franklin would be proud.

Michael A. Morrison is the David Ross Boyd Professor of Physics and General Education at the University of Oklahoma.

CONFERENCE AGENDA

Saturday, November 1, 2003
McMurtry Auditorium, Duncan Hall
Presiding Chair: Rita Colwell, Director, National Science Foundation

Session I: Welcome and Introductions

Eugene Levy
Howard R. Hughes Provost, Rice University

Thomas Meyer
Associate Director for Strategic Research, Los Alamos National Laboratory

Session II: Energy, Environment, and Security

Keynote Address

John Holdren
Director of the Science, Technology, and Public Policy Program, John F. Kennedy School, Harvard University

Session III: Energy and Environment Science Panel

Warren Washington
Head of the Climate Change Research Section, Climate and Global Dynamics Division, National Center for Atmospheric Research, and Chairman of the National Science Board

Michael MacCracken
President of the International Association of Meteorology and Atmospheric Sciences, Former Executive Director of U.S. Global Change Program, Former Director of the National Assessment Coordination Office

Rosina Bierbaum
Dean of Natural Resources and Environment, University of Michigan, and Former Associate Director for Environment of the White House Office of Science and Technology Policy

Robert White
Principal with the Washington Advisory Group and Former President of the National Academy of Engineering

Richard Anthes
President, University Corporation for Atmospheric Research

Remarks and Lunch

Malcolm Gillis
President, Rice University

Session IV: Energy and Environment Technology Panel

Henry Kelly
President of the Federation of American Scientists and Former Assistant Director of Technology in the Office of Science and Technology Policy

Larry Papay
Sector Vice President for Integrated Solutions Sector, SAIC

Thomas Meyer
Associate Director for Strategic Research, Los Alamos National Laboratory

William Wulf
President, National Academy of Engineering

Richard Smalley
University Professor, Rice University

Session V: Nuclear Energy and Security

Keynote Address

Dr. Ernest Moniz
Professor of Physics, Massachusetts Institute of Technology and Former Undersecretary of the Department of Energy

Session VI: Nuclear Energy and Security Panel

Anita Jones
Lawrence R. Quarles Professor of Engineering and Applied Sciences, University of Virginia, National Science Board, Former Director of Defense Research at the Department of Energy

Gregory Canavan
Senior Laboratory Fellow, Los Alamos National Laboratory

Raymond Juzaitis
Associate Director for Weapons Research, Los Alamos National Laboratory

Sunday, November 2, 2003

James A. Baker III Institute for Public Policy
Presiding Chair: Dr. M. R. C. Greenwood, Chancellor, University of California at Santa Cruz

Session VII: Science and Technology Policy

Keynote Public Address

Dr. John Marburger III
Pres. G. W. Bush's Science Advisor

Session VIII: Science and Technology Policy Advice in Government

Moderator: Robert Palmer, Democratic Staff Director, House Science Committee

Policy Perspectives

H. Guyford Stever
Pres. Ford's Science Advisor

D. Allan Bromley
Pres. G. H. W. Bush's Science Advisor

John Gibbons
Pres. Clinton's first Science Advisor

Neal Lane
Pres. Clinton's second Science Advisor

Remarks: Oil, the Middle East, and the US Response, Post-September 11: A Push for Energy Technology Breakthroughs

Edward P. Djerejian
Director, James A. Baker III Institute for Public Policy

Session IX: Education and Technical Workforce

Keynote Address

Shirley Malcom
Head of the Directorate for Education and Human Resources Program, American Association for the Advancement of Science, Former member of the Pres. Clinton's Council of Advisors on Science and Technology Member of the National Science Board

Session X: Education and Technical Workforce Panel

Duncan Moore
Professor in the Department of Optical Engineering, University of Rochester and Former Associate Director for the Office of Science and Technology Policy

Thomas Kalil
Special Assistant to the Chancellor for Science and Technology, University of California, Berkley, Former Deputy Assistant to President Clinton for Technology and Economic Policy and Deputy Director of the White House National Economic Council

Joseph Bordogna
Deputy Director, National Science Foundation

Bruce Alberts
President, National Academy of Sciences

Session XI: International Cooperation
Moderator: Robert Curl, University Prfessor Emeritus, Rice University

Keynote Address

Norman Neureiter
Former Science and Technology Advisor for the Secretary of State for Sec. Albright and Sec. Powell and Former Vice President of Texas Instruments Asia

Session XII: International Cooperation Panel

Mildred Dresselhaus
Institute Professor of Physics and Electrical Engineering, Massachusetts Institute of Technology and Former Director of the Department of Energy Office of Science

Houston "Terry" Hawkins
Special Advisor to the Director, Los Alamos National Laboratory

Frederick Bernthal
President of Universities Research Association, Former Deputy Director and Acting Director of National Science Foundation

EXECUTIVE SUMMARY

Neal Lane, Kirstin Matthews, Amy Myers Jaffe, and Rosina Bierbaum

As the world moves further into the 21st century, it is becoming increasingly apparent that revolutionary advances in energy science and technology will be necessary to meet future challenges. Today, close to one-third of the world's population lives without modern energy services, perpetuating the poverty and human suffering that leads to desperation and regional instability and conflict. Affordable energy is a crucial input to prosperity and a necessary element to sustainable development. Energy accounts for seven percent of world trade and represents a substantial variable in the balance of trade for most nations, including the United States. Additionally, energy production and use are significant contributors to many of the most difficult environmental problems at the local, regional, and global levels. Providing increasing levels of affordable energy to the world's rising population without undermining the environmental foundations to a sustainable planet is one of the most technologically challenging questions facing international science today.

Each energy source has problems. In the less developed world, the burning of traditional biomass is the source of indoor pollution that leads to the death of over two million women and children every year. Nuclear energy generation is the major producer of radioactive waste in the world, and the burning of fossil fuels is the major contributor of emissions of greenhouse gases that are increasing the average temperature of the Earth and may already be altering the global climate. These problems are not easily solved, and the shift to new technologies that offer solutions will be slow to replace existing infrastructure and will incur considerable cost. For these reasons, there is lethargy in the formation of sound public policy, which consequentially threatens our future prosperity.

Electric power plants on the drawing board for the period between 2010 and 2015 will still be in operation by 2050. The International Energy Agency predicts that over $16 trillion will need to be invested in new energy infrastructure between 2001 and 2030 to meet projected energy demand, of which 60 percent will be required to expand the global electricity network. The nature of the technologies chosen to produce this energy will have dramatic consequences for global environmental conditions and sustainable development. Following a business as usual approach, carbon emissions from fossil fuel burning could rise to over 20 billion tons in 2100 from six billion tons/year in 2000. Even if we could double the rate of improvement in energy efficiency worldwide over the next century to two percent from one percent per year, the requirement for carbon-free energy in 2100 would still be more than 3.5-fold above today's contribution from nuclear energy, hydropower, solar, wind, and biomass in order to assure stabilization of atmospheric CO_2 at less than 550 ppm, which is twice the pre-industrial level.

The most developed countries, with 13 percent of the world's population, account for half of the world's annual energy use. The rate of use of energy in the wealthiest countries, per person, is about eight kilowatts, compared to one kilowatt in the less developed world. Developing countries, such as China and India, are rapidly increasing their energy consumption as they improve standards of living. The consequences of this rise in demand for energy in the developing world, coupled with consistent rises in energy use in the United States, will pose serious risks to the global system if new technologies are not developed. Indeed, we are already seeing serious global conflicts that are, in part, due to increasing concerns about meeting the world's energy needs. Yet, expenditures on energy research and development have declined over the past 20 years in every Organization for Economic Cooperation and Development (OECD) country except Japan, which despite its smaller size spends almost twice as much as the United States on energy research and development (R&D).

Because of rising concerns about the urgency of the energy problem and implications for the United States and federal policy, the James A. Baker III Institute for Public Policy, along with Rice University's Department of Physics and Astronomy and Los Alamos National Laboratory, convened the two-day workshop entitled "Bridging the Gap Between Science and Society: The Relationship Between Policy and Research in National Laboratories, Universities, Government and Industry" The conference, held November 1-2, 2003, focused on critical issues of energy and related science and technology policy and included public presentations and discussions by more than 30 top scientists and energy and policy experts. The audience was comprised of more than 200 policymakers, scientists, opinion shapers and business leaders.

Conference sponsors included the Baker Institute, the National Science Foundation (NSF), Los Alamos National Laboratory (LANL), and the Department of Physics and Astronomy at Rice University. Among the topics covered were overall energy policy and societal impacts; climate change; nuclear energy policy; science advice to policymakers; math, science, and engineering education; and the role science plays in advancing international relations.

The conference participants took the occasion to honor the contributions of Neal Lane, former Director of the National Science Foundation and former Assistant to the President for Science and Technology during the Clinton administration.

The conference was not a workshop aimed at forming a policy consensus. Rather, the gathering was one where speakers and other participants shared their individual views openly. They were not asked to represent any particular organization or point of view. This forward draws heavily on edited transcripts and presentation materials and includes many important points raised at the meeting. However, no summary can do justice to the rich diversity of topics and perspectives discussed over the two days.

With this qualification, this summary and the transcript report of the meeting itself highlights the need the following: for increased energy R&D leading to innovative new technologies; increased partnerships between universities and national energy laboratories; the means and incentives to rapidly develop, demonstrate and deploy cheaper, more efficient, and environmentally sound energy supplies; more attention to deficiencies in the nation's technical workforce; and enhanced international cooperation in the development of a global energy policy.

Energy and International Cooperation

The international community currently faces the most difficult energy market it has seen in two decades. Oil price volatility has experienced record swings; and the future of the Middle East, home to 60 percent of the world's known oil resources, remains fraught with great uncertainties. Dependence on Persian Gulf oil is likely to grow over time given the concentration there of the world's remaining resources of oil.

Ethnic tensions, nationalist ambitions, religious extremism, and economic competition continue to divide the world's people. To remain a global leader across a wide variety of areas of commerce and to continue to defend our national security, the United States will need to significantly increase its spending on science and education.

At present, America remains the only credible bearer of the mantle of global leadership.

Maintaining this role and applying the nation's science and technology skills to the challenge of sustainability is the best way for the United States to move forward. For this purpose, the United States should promote open exchanges between scientists around the world and thus, be able to draw on the best and the brightest to tackle difficult technical challenges posed by increasing world demand for energy and consequential environmental degradation, including global warming and climate change.

Science in the United States has always benefited from international relationships. Even in times of discord, scientists have continued to interact with their counterparts in other countries and served to keep the lines of communication open. And international cooperation on scientific matters has, in the past, proved to be an effective political "icebreaker."

Science and technology are also vitally important in assuring nuclear security and, more generally, U.S. national security. The tragedy of September 11 showed that enemies of the United States and other developed nations are willing to use terrorist attacks on thousands of innocent people as an instrument of fear in an effort to achieve their desired ends. As has been the case in the past, e.g. World War II, science and technology will be called upon to protect people from harm. New technology will not, in itself, guarantee security, but technology can make terrorist events less probable and reduce their impact. Because terrorism is a global issue, the United States should be open to cooperation with individuals from other nations. It is to no one's benefit to deny the participation, through visa restrictions and export controls, of scientists from other nations who are willing to work cooperatively with the United States.

Energy and Environment

Burgeoning environmental problems, predicted to grow over the coming decades, dictate that we develop new, cleaner sources of energy. Scientists, particularly experts in climate research, have become increasingly convinced that the consequences of burning fossil fuels at current or expanding rates will have serious, deleterious impacts on the global climate.

The International Panel on Climate Change (IPCC), a UN group involving 2000 scientists from 150 countries, concluded that temperatures are likely to increase another 1.4 to 5.8°C in the next 100 years in addition to the 0.6°C increase already observed (IPCC Third Assessment Report: Climate Change, 2001). In the last part of the 20th century,

CO_2 levels have been rapidly increasing. Scientists have measured these increases in the atmosphere directly since 1958. To attain estimates of temperatures prior to that time, proxy methods have been used, e.g. analysis of air bubbles trapped in cores of ice taken from large ice sheets in Greenland and Antarctica. Sophisticated computer climate models, based on the best scientific information available, show the correlation of increased concentrations of greenhouse gases in the atmosphere with the rise in the average temperature of the Earth. It is the consensus position of many of the world's top climate experts that "most of the warming observed over the last 50 years is due to human activities." Although the temperature increases may seem small with the upper bound equivalent to the temperature shifts between ice ages, it has happened in 100 years, instead of during a millennium. This rate of change is more rapid than ecological systems have adapted to in the last 10,000 years. The manifestation of global change depends on three things: the rate and absolute change in temperature; the composite effect of climate change acting in concert with other environmental insults such as habitat fragmentation and biodiversity loss; and the ability of different regions and populations to cope with the changes.

Many effects of climate change are already apparent. There is a rapid decrease in Arctic sea ice as well as land-based ice such as Greenland. Mountain glaciers are receding worldwide, and lakes are freezing later in the fall while thawing earlier in the spring. Blooming dates of botanical gardens worldwide are earlier each decade. These climate changes do not occur in isolation, but in concert with other environmental stresses. A warmer world enhances smog formation and reduces air quality. Although a warmer world with increased carbon dioxide could encourage more plant growth, it could also increase insect infestations due to the milder winters and forest fires due to drier conditions.

Climate change will also have an impact on the human population. With the hydrological cycle speeding up, we can expect more floods and more droughts. These extreme events will cause human pain and economic loss. Moreover, there has been continual development along the fragile coastlines around the world. With more extreme weather, such as frequent flooding and wind damage, our ability to cope with the resulting consequences comes into question. Can we develop options to protect the at-risk populations? If the sea-level were to rise only one meter, a low-lying state like Bangladesh would lose 13 percent of its land area and displace 18 million people. This would create environmental refugees of historic proportions. Furthermore, issues of security are likely to be exacerbated by climate change as the world's population competes for resources whose availability will be reduced by climate effects.

Energy Technology and Innovation

The very large projected growth in world demand for carbon-free energy in the coming decades, even under the most conservative assumptions, cannot be met with existing technologies. New technologies will require a much larger energy R&D effort—government and industry—than we have had in the past. That will require significant multi-year increases in the federal budgets for energy-related research in several agencies; improved coordination across government agencies and national laboratories; enhanced partnerships between national laboratories, universities and industry; and increased international cooperation. The American scientific inquiry in the energy arena is scattered, unfocused, and incommensurate with the task. In part, this is because the United States lacks a clear roadmap to a better energy future. Finding a solution to burgeoning world energy needs and environmental impacts, including climate change, not only requires a coordinated effort among scientists around the world focusing on new energy technologies and innovations, but also demands a dramatically higher level of public and private funding. In the past, there has been resistance to increased energy R&D funding. Some policy makers have argued that the market should take care of the problem—if the energy sector needs new technologies, the industry will fund the R&D necessary to produce them. But, this argument fails to recognize the different roles and priorities of government and the private sector.

While in the past, it has been proposed that a drop in government spending would be outweighed by a rise in private sector funding that has not been proven correct. U.S. programs that support energy research, development, demonstration, and deployment simply are not up to the challenges facing the nation and the world. There was a "conspicuous peak" in spending in the late 1970s associated with "Project Independence." But, since that time, some failed programs, such as synfuels and the breeder reactor, have left concerns about whether the government can meet the test to garner the best uses of public resources in the energy area. Since 1997, the President's Council of Advisors on Science and Technology (PCAST) has proposed significant increases in spending on energy technologies—particularly in the areas of efficiency and renewables--but recommended allocations have generally been trimmed back during the appropriations process.

Strategies for making more efficient use of energy will be central to meeting future energy requirements and addressing environmental problems. Gaining efficiency between energy inputs and production output will be important not only to the energy/environmental dilemma facing the country, but also as a way to increase overall productivity of the U.S. economy. Dramatic breakthroughs are likely to come from research in the fields of biotechnology, information technology, and nanotechnology. These technologies are ones in which the United States must ensure the competitiveness of its industries. However, the current U.S. political energy debate is not focused on the key question of how to accelerate the development and use of innovative technologies.

There is a need to change the terms of the debate to acknowledge that a new foundation is needed for future energy prosperity, requiring a vast effort to provide a new "non-traditional" source of carbon-free energy, readily available by the middle of the 21st century. This new carbon-free energy source must be at least twice the size of all worldwide energy consumed today. Also, if the world is to leave petroleum products as its primary fuel, it must develop another fuel that can be easily transported over long distances.

Natural gas and hydrogen have been offered as alternatives. However, technologies for transporting natural gas and hydrogen across oceans are not nearly as efficient and cost-effective as those for transporting oil. Biofuels are also being investigated, with ethanol produced from cellulosic biomass or organic waste processed by thermal depolymerizxation appearing to be the most promising in terms of full cycle energy use gains that result in real time displacement of oil consumption. The United States generates over 250 million dry tons of forest, crops, and urban wood wastes which could be recycled to produce more than 1 million barrels a day of transportation-grade bio-fuels, according to Oak Ridge National Laboratory.

Another attractive candidate for the "new oil" fuel of the coming century is electricity, with local storage technology and long distance transmission holding the key to a new energy world. The single biggest problem of electricity is storing it. Approaches that entail production and storage of electricity on a vast scale are daunting, but technologies could be developed to attack the energy storage problem locally, at the scale of a house or small business. A local storage-based system would allow users to buy energy supplies off the grid when supplies are cheapest, unlike the current centralized plant system where almost twice as much generation capacity is needed to fulfill peak time demand.

One vision of such a distributed store-gen grid for 2050 includes a vast electrical continental power grid with more than 100 million asynchronous local storage units and generation sites, including private households and businesses. This system would be continually innovated by free enterprise, with local generation buying low and selling high to the grid network. Optimized local storage systems would be based on improved batteries, hydrogen conversion systems, and fly wheels, while mass primary power input to the grid could come from remote locations with large-scale access to cleaner energy resources (solar farms, stranded natural gas, closed-system clean coal plants, and wave power) to the common grid via carbon nanotubes, high-voltage wires that minimize loss. Excess hydrogen produced in the system could be used in the transportation sector, and excess residential electricity could be used to re-charge plug-in hybrid electric vehicles. Innovative technological improvements in long distance, continental power grids that could transport hundreds of gigawatts over a thousand miles instead of 100 megawatts over the same distance would permit access to very remote sources including large solar farms in the deserts, where local storage can be used as a buffer. Remote nuclear power sources could be located far from populated areas and behind military fences, to address proliferation concerns. Clean coal plants could be located wherever it is convenient and economical to strip out and sequester the CO_2. What is envisioned here is a revolutionary change in how energy is produced, distributed and delivered. Such an undertaking would require a major national effort, perhaps analogous to the Apollo program.

The deployment of many new energy technologies is required to tackle the energy and environmental challenges facing the United States and the world. Perhaps, the most important initial step, while building up the energy R&D effort, is to take a serious look at the innovation process and attempt to understand what policies are needed to hasten the movement of new energy technologies into the market place. Experience has shown that the further off the technology is in the future, the lower is its estimated commercial cost. Technologies always look more benign in the theory stage, but experience has shown that deploying new technologies on a large scale often is accompanied by unacceptable environmental impacts. For these and other reasons, many promising revolutionary ideas never make it to market because of the incremental costs associated with early deployment. Some succumb to the "valley of death"—running out of the time and money needed to turn a demonstrated product into a widely deployed commodity. New energy technologies have had a particularly difficult time over the last two decades because of the competition from relatively cheap natural gas supplies.

The federal government should encourage research on many types of technologies (a basket approach) and avoid the temptation to pick winners. It will take government incentives, such as renewable portfolio standards, to drive technological innovation. One reason technologies that rely a local electricity grid with distributed generation are so promising is the shift to a digital society and the urbanization process underway around the world. By 2015, there will be 49 cities of five million people or more compared with the situation in 1950, when there were only eight cities of five million or more. Historically, rural areas were needed for agriculture, to supply the food needed by the larger population. In the future, one can imagine that a significant portion of the rural countryside will be devoted to supplying much of the energy needs of the larger population.

One new energy technology advocated by the George W. Bush Administration is the use of hydrogen fuel cells. Of course, hydrogen is not a primary energy source and must be extracted from other sources such as methane. Consequently, for hydrogen to become a major energy fuel, new technologies must be developed that are capable of producing hydrogen from energy sources available on a major scale. U.S. sources of methane are currently in short supply. In the future, coal could be used as a source of hydrogen because of its abundance; but to utilize this source, CO_2 would have to be sequestered in some fashion. According to a Princeton University study, currently the most viable approach would be to construct facilities that permit the precombustion capture of CO_2, in which CO_2 and hydrogen are produced, the hydrogen is then burned to produce electricity and the waste CO_2 is injected into subsurface geological reservoirs. This would require about a tenfold expansion of plants resembling today's existing hydrogen plants and a scale up of current enhanced oil recovery programs that utilize CO_2 to spur oil production. New demonstration projects would also be needed to develop existing subsurface structures that could be refurbished to serve as geologic storage depots for sequestered CO_2. Today, about 0.01 gigaton of carbon per year is injected into geologic reservoirs to enhance oil recovery so a scale up of more than 100 times would be needed over the next 50 years to make a significant contribution to emissions reduction. This scale, according to Princeton University studies, is the equivalent of 3,500 projects of the size of Norway's Sleipner CO_2 project, which currently strips CO_2 from natural gas as it is being produced and reinjects 0.3 million tons of carbon a year into a non-fossil-fuel bearing formation. A major science effort is underway to assess whether the risks of leaks from such storage are large enough to threaten human and environmental health.

In a longer-time frame, nuclear energy could be used to make hydrogen either by new reactor technologies that would allow the splitting of water into hydrogen and oxygen or by the use of high temperature chemical cycles. There also is the hope that hydrogen will eventually be produced from renewable energy sources such as solar power driven reactors (to split water into hydrogen and oxygen). There are also still substantial technical barriers related to hydrogen storage, delivery, and distribution that will have to be overcome.

The capital investment required to create a hydrogen economy will be significant—General Motors has estimated the capital infrastructure costs to run in the tens of billions of dollars. Shifting to a hydrogen economy will also require improvements in fuel cell technology, including lowering costs and finding better catalysts, chemical separations, interface chemistry, and new material membrane chemistry. The emergence of these technologies will require significant R&D investments in photochemistry, catalysis, chemical materials, chemical separations, interfacial chemistry, materials science, new polymeric and ceramic materials, theory and modeling, engineering, reactor design, and systems integration.

Nuclear Energy (Power)

An obvious option for carbon-free energy is nuclear energy, currently used to generate electrical power. However, nuclear power faces several barriers to larger scale deployment, including cost competitiveness, problems of waste disposal, and security and proliferation concerns, given the close relationship between spent nuclear fuel and nuclear weapons development.

In the post-9/11 era, nuclear power faces specific challenges in the area of nuclear weapons proliferation and nuclear terrorism. The current disagreement over Iran's pursuit of nuclear capability points to shortcomings of the nonproliferation treaty (NPT) regime. Countries can come very close to having nuclear weapons capability by pursuing a nuclear power industry, and indeed do so seeking and receiving the assistance in key technologies from other countries as part of the NPT or Atoms for Peace regime. Russia can argue that its actions to assist Iran in developing nuclear power capability by providing fuel for the Bushehr nuclear plant are consistent with NPT obligations. But the Iranian-Russian nexus on nuclear power does not meet other imperatives, namely to prevent Iran from gaining access to knowledge and materials that it could use to develop nuclear weapons.

The core non-proliferation issue is to keep weapons-usable material, that is, highly enriched uranium (HU) and plutonium, under control and out of the hands of proliferation nations and especially out of the hands of non-governmental terrorist groups. This includes three tasks: 1) protecting existing materials; 2) reducing and eventually eliminating excess stocks of weapons-grade materials; 3) shaping future technology development and institutional frameworks to avoid future problems if nuclear power sees global expansion. Between the United States and Russia, 1,000 tons of HU and 200 tons of weapons-grade plutonium exists. Another 25 kilograms and 8 kilograms reside with the International Atomic Energy Agency (IAEA), while other countries pursuing plutonium recycling in mixed oxide fuel (MOX) have about 200 tons in storage. The U.S. Department of Energy (DOE) is playing a key role in helping Russia secure its stocks of nuclear materials and blending weapons-grade uranium into nuclear reactor fuel to be processed in the United States.

It can be argued that while a HU blend-down program makes economic sense, plutonium recycling, using MOX technology does not. Not only is the MOX fuel cycle not economical, it also makes available an operation to separate weapons-usable plutonium. Many experts believe that the IAEA should expand its safeguards by adding an additional protocol that would give the IAEA the right to search undeclared sites in various countries.

Nuclear energy may well be an increasingly relied on as a source to meet rising energy demands. But, nuclear energy is not likely to become commercially competitive as a fuel in most markets unless the financial risk factor is reduced and regulations are put in place to internalize the costs of carbon emissions. In addition, the industrialized countries will have to establish clearer rules for the operation of nuclear power plants that define fuel cycles, rather than the plants, themselves, as the critical concern. U.S. experts note that not only is the MOX fuel cycle not economic, it also makes available an operation to separate weapons-usuable plutonium to nuclear power countries. A sensible policy would be to establish the mechanisms for providing the necessary guarantees to deliver fresh fuel and accept back the spent fuel. The United States also needs to commit to working with other nations on what will undoubtedly be a long-term research and development program on advanced fuel cycles

The future of nuclear power also depends on the maintenance of human infrastructure which many studies show has been declining over the last two decades as reductions in research funding have led universities to close research reactors. In the area of nuclear science and engineering, the education pipeline is essentially depleted, with too few undergraduate and graduate students as well as researchers entering the field. This situation in education and research will have to be reversed if the United States is to have a strong future capability to enhance nuclear power generation. U.S. nuclear industrial capability is following the same declining path as educational capability. A larger issue that needs serious attention is the technical understanding gap that exists between nuclear experts and the general public. This is particularly challenging when nuclear power and nuclear waste disposal are hot political issues, giving rise to extreme rhetoric reported by the media. Public acceptance of nuclear power cannot be developed in the absence of at least a minimal level of technical and scientific literacy.

Energy, Security and R&D in the National Labs

The federally funded national Department of Energy (DOE) laboratories are where much of the nation's advanced energy technologies and know-how are located. There is little disagreement that the federal government has a responsibility to fund basic research as well as the other R&D that industry will not support. Important pre-commercial work is done in universities, where the next generations of scientists and engineers are educated, and in the National Laboratories, which have unique facilities and researchers focused on energy and related technical issues. And as with other areas of science, there is much to be gained from open sharing of results and collaboration with researchers and institutions in other parts of the world.

In order to make serious progress in developing new energy systems, the federal government will have to make a considerable investment, well beyond what it is doing today. But, it should be kept in mind that energy as well as climate change and other energy-related environmental challenges are long-term issues that will become enormously expensive down the road. While the costs of substantially increasing the federal energy R&D budget by a few billion dollars per year, may appear to be high, it should be pointed out that the alternative is much more expensive. The International Energy Agency (IEA) projected that the total investment requirement for energy supply infrastructure will top $16 trillion between 2001 and 2030 (IEA World Energy Outlook, 2003).

The Bush Administration has noted that the advances in new technology that we have seen over the last 50 years are closely related to prior investments in science and basic research, particularly in the physical sciences. However, aside from the Apollo period, U.S. federal funding for science and technology research and development has remained at a relatively constant fraction of about 10 percent of discretionary funding. Increases well above this level, such as occurred during the Apollo project, were unsustainable in the long term. With priorities continually fluctuating due to global events and administration changes, it is clear that science advocates must find a way to make the goals of research and development align better with the needs of the country. Simply arguing that more funding is needed for R&D or basic research has not been effective for many decades. In recent administrations, the identification of particular initiatives, e.g. global change research, information technology, and nanotechnology have caught the public's attention and led to increased R&D funding in selected fields, but often at the cost of decreasing funding in others. In some fields that require large facilities, e.g. particle accelerators, and astronomical observatories, international cooperation has been critical to success, since few if any nations can afford such facilities on their own.

It could be argued that biomedical research is in a special class, that the public has bought the argument that "more is better." But the public likely viewed this effort as a "war on cancer", a rationale that requires little further explanation. The National Institutes of Health (NIH) budget has grown, in real terms, for several decades, while most of the rest of research funding has remained flat or declined. NIH funding now represents half of all federal research funding. In recent years, even NIH funding has not increased significantly and in some years it is losing to inflation. The former director of NIH, Harold Varmus, has often made the point that since the new drugs and medical technologies come out of basic chemistry, physics, engineering and other fields, we are under-investing in the enabling science that supports medical advances as well as all the rest of a technologically based economy. That lack of balance does not argue, necessarily for less biomedical research, but rather for more funding in other areas. If, indeed, an "Apollo Energy" project is needed, the arguments will have to be even more compelling.

Much of this nation's capability to increase its effort in energy R&D resides in the U.S. DOE defense and general purpose national laboratories. Their role is broad and deep. In the case of the DOE defense labs, a principal focus is certifying the integrity of the nuclear weapons stockpile. However, this assignment cannot be achieved over the long term without a strong scientific base. Problems in national defense are complex and require the integration of expertise from a wide range of disciplines. Since the nature of the problems and their solution changes with time, there is a greater need for readily accessible, technically-broad staff that can serve as a robust national resource that can be rapidly directed toward critical national problems, e.g. homeland security. Especially in the absence of full-scale nuclear testing, the pertinent activities require large-scale facilities for computation, experimentation, and simulation. The work entailed is not just engineering, and the best defense technology cannot be achieved without the underpinnings of basic science. With this combination of capabilities, the national labs are also well-suited to contribute to non-weapons scientific problems, ranging from fuel cells to the human genome, in addition to defense and homeland-security applications. The expertise at the national labs also contributes to national policy and threat reduction, as well as provides an interface with universities. These labs have been leaders in the energy science and technology business for many decades, and many of the labs have productive collaborations with industry.

Today, the nation's security depends very much on protecting its critical infrastructure (e.g. the electrical and communications grids, and the banking and financial system) that supports most business, government, transportation, and other vital everyday activities of the country. This infrastructure is increasingly dependent on the reliability of the internet and the computers and other technologies that support it. Currently, there are no rules and treaties related to the use of the Internet and cyberspace. Because the Internet has a substantial effect on the world's economies, the risk for terrorism in cyberspace is of great concern. High-performance computing and communication are also areas in which the national labs have been strong. Their expertise in this area will likely be even more important in the future.

Science, Technology, Engineering and Mathematics Education and the Workforce

The science and technology community, collectively, is getting older each year. A 1999 report from the National Science Board (NSB) indicated that 57 percent of the scientists and engineers are over age 40, with 28 percent over 50. Another study by the NIH found that the average age of applicants for traditional research project awards (the NIH R01 is a single investigator grant, which constitutes the vast majority of NIH's grants) increased from 1980 to 2001. In 2001, only 3.8 percent of NIH applicants were under 35 (compared to 22.6 percent in 1980), while 60.2 percent of the applicants were 40 and over (compared to 31.6 percent in 1980). This reflects substantial side benefits of the Apollo program, which recruited an entire generation of young people to enter the sciences. Today, at least in part due to lacking bold initiatives and visible funding, interest in the sciences has declined.

There are many problems, or challenges, facing science education and the science, engineering, and technical workforce. Two, in particular, received emphasis in the conference discussions.

First, the assertion that the nation needs an adequate base of talented scientists and engineers is not debated. But, it is not clear how to quantify that need. Today, we have fewer students graduating with bachelor's degrees in science and engineering than in the past. But, the hiring demand figures do not point to an obvious problem. In part, this may be because we have been able to recruit talented individuals from across the globe to fill our graduate classes and research positions in university laboratories and, upon graduation, satisfy the needs of industry. And, with the unemployment rates for scientists in some fields actually growing higher, getting students interested and keeping them interested in science is a major problem. This is even more challenging for young people growing up in families and communities where there are no peers in science and engineering to look to as models. In part, because of this latter problem, there remains a chronic lack of diversity among graduates in science and engineering. The NSB concluded in 1999 that 64 percent of the scientists and engineers were white males. Most organizations, public or private, accept the premise that greater diversity in science and engineering is vital to the quality of the science and technology enterprise in the country. Thus, recruitment of more women, minorities, and persons with disabilities in the science and technology workforce remains an important national goal both for government and the private sector. In addition, we need some fresh ideas and renewed commitment to this goal.

It is also observed that science has a marketing problem. Science needs to appeal to youths; it needs to be more inclusive of the community college system; and it might require another high-profile science and engineering initiative like Apollo to capture the enthusiasm and imagination of our youths.

In the past the United States has been fortunate to be able to attract many of the best and brightest young women and men from other countries. Had that not been the case, the nation might have found itself in a much weaker economic position in the world than it presently occupies. However, in part because of stringent visa restrictions, but also because there are attractive opportunities to study and work in other countries, fewer foreign-born young people are applying to U.S. universities. Efforts are being made to address the visa problem. But, more stringent export controls (on access to research equipment and technologies) placed on foreign students could, on the heels of the visa problems, have a devastating effect on the immigration of technically talented individuals. There are major policy issues here that must be addressed.

A second challenge, specific to science education in this country, is that the educational system, at all levels, does not provide an adequate base for professionals in non-technical fields, even in related fields such as health care and education. Science is not reaching the majority of the children in our K–12 schools and young adults in colleges and universities. In the pre-college arena, the National Academies have put forward national standards for math and science teaching to provide thoughtful guidance to K–12 schools and systems. However, these are not uniformly accepted due to controversies related to religious beliefs of certain segments of the general population.

The Academies' *National Science Education Standards* are based on three principles. First, science is for all students - not just those planning to join the science and technology workforce. Second, learning science requires active engagement. Students should be encouraged to think and problem solve, not just memorize facts for a test. All young people should sharpen their abilities to use logic and evidence and to argue their positions in the manner of scientists, even though they may not choose careers in science. Third, school science should reflect professional science and the skills needed in the real world. More molecular and cellular biology and newer areas of research should be taught in K–12. Even undergraduate science and engineering courses should include real-world applications guided by companies that are interested in hiring qualified people. Since U.S. businesses find that inquiry-based science education, or "learning to learn" suits their needs better than the current system of committing information to memory, they should become more effective advocates for the type of education that will serve their needs.

The majority of K–12 science teachers lack key resources: the background to teach to these standards; the classroom resources required; the time to learn the material and develop the lessons; or even the freedom to design their own courses. One important step towards resolving this problem would be to provide higher compensation for teachers, including a 12-month salary, so that they would have the summer to prepare for the next year and get up to date on the latest developments in their subject areas. This requires money and commitment. In particular, the "teach to the test" approach being pushed by politicians is likely to drive away the best science teachers.

At the college and university levels, despite heroic efforts by some faculty and some departments, most non-scientists, including education majors, can expect only a shallow exposure to science, often graduating with neither in-depth understanding of the scientific process we call research, nor the scientific revolutions that have occurred in biology, chemistry, physics, earth sciences, engineering and many other fields over the last few decades.

Conclusion

The conference on which this report is based, "Bridging the Gap between Science and Society: The Relationship between Policy and Research in National Laboratories, Universities, Government and Industry" was not a workshop. No effort was made to reach consensus on findings and recommendations. But, based on the presentations and discussion, it is possible to draw some key conclusions from the conference.

First, the centrality of energy to economic prosperity, sustainable development, environmental quality, and the stability of nations in many parts of the world make it a critical public policy issue for the nation. H. Guyford Stever, science advisor to President Ford, stated it succinctly when he emphasized that the "top priorities for our country should be energy, the environment, and the economy." A sensible U.S. energy policy must take into account environmental and economic issues and seek to balance tradeoffs.

Second, no realistic projections of the impact of current technologies into the future come close to meeting the projected demand for clean, carbon-free energy by the end of the century. New breakthrough technologies will be needed for the production, distribution, and efficient use of energy; and these can only come from science and technology R&D. Many participants emphasized that the United States invests far too little in energy R&D, and even less in the demonstration and dissemination of new energy technologies. Federal investments in these areas will have to be increased considerably.

Third, given the complexity and global nature of the energy challenge, there is a need for significantly enhanced cooperation between universities, the national energy laboratories, and U.S. industry and between researchers and organizations in the and those in other nations. Current policies and practices make such cooperation difficult, (e.g. visa restrictions, export controls, and denial of access of foreign students and scientists to national laboratories and, increasingly, to federally funded university projects as well).

Fourth, the nation faces a crisis in the quality, perhaps even the size, of its science and engineering workforce, which is vital to the nation's energy future as well as to our prosperity and security. In recent decades, the nation has made up for a shortage of U.S.-born men and women who choose science and engineering careers by welcoming talented individuals from abroad. But in the post-9/11 era, there are high barriers to immigration of these talented people. The poor quality of K–12 science and mathematics education is also part of the problem. But there are social and economic issues as well. Some argue that the market will take care of the problem. But, the NSB, in commenting on this issue, has noted that career decisions begin in students' early years, and it estimates that it would take about 14 years of lead time to make a significant change.

Our current energy predicament requires a bold new energy science and technology program, as well as an enlightened federal policy to map out the path to development of new sources for a better energy and environmental future for the 21st century. Such a path will have to be guided by an enlightened federal energy policy that goes well beyond anything we have had or have today. Elements of a new energy policy must include the means and incentives to rapidly develop, demonstrate and deploy cheaper, more efficient, and environmentally-sound energy supplies to protect the global environment while improving the quality of life in developing countries. With visionary leadership at the highest levels of government, and sound national science, technology and energy policies to match, larger numbers of talented and motivated young people might well find the world's energy challenge sufficiently compelling to attract them into careers in science and engineering.

In our form of representational democracy, policymaking can be a slow and cumbersome process, in which many voices must be heard. On a matter as important to the future of the nation as energy, the public and its elected representatives need to understand the issues, some of which are technical. Neal Lane has often made the point, which he repeated at this conference, that only by enlisting the active involvement of scientists, engineers and other technical professionals, will we stand a chance of raising the level of public understanding of technical matters like energy. This is the role Lane calls the "civic scientist", which he defines as a scientist, engineer, mathematician, medical doctor or other technical professional who uses his or her knowledge and skills to inform the public and policy makers on technical matters—and does so with honesty and integrity.

What is called for, according to Lane, is a "dialogue or conversation, rather than a lecture." Moreover, there continues to be a severe shortage of scientists and other technical professionals in policy positions in most parts of the federal and state governments, including the White House and Congress as well as the governors' offices and state legislatures. Policy is often, perhaps usually, being implemented outside the framework of sound scientific advice. The role of scientists should be policy-relevant, but never policy prescriptive. Mixing science with partisan politics will result in bad science and bad policy. Scientists always need to keep this in mind. But, it is a two-way street. Government must show the same restraint and treat science—the support and regulation of research, the use of scientific information and advice and the information it provides to the public—in a fair and impartial manner, well separated from partisan or ideological influence.

In the case of energy policy, scientists should focus on guiding federal decision-making so that limited resources are well spent, and solutions to critical challenges such as energy and the environment can be developed and implemented in an efficient and cost-effective manner. National strategies should reflect the best range of alternatives so that markets are able to select technological solutions that will meet national goals. The United States has a leading role to play, working in partnership with other nations of the world, including the least developed countries, in dealing with this truly global energy, environmental, and security challenge.

Energy is, perhaps, the number one future challenge facing this nation and the world. The United States is fortunate to have the resources, human and financial, to take on this challenge. Success will require cooperation among nations across the globe. But success will not be possible without the leadership and active participation of the United States. And time is running out!

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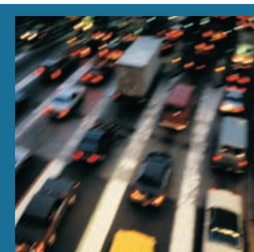
ENERGY



ENERGY AND THE HUMAN CONDITION

John P. Holdren

In this presentation I will discuss the connections between energy and human well-being and how well we are doing in rising to the challenge that those connections pose. I will start with the nature of the links between energy and human well-being, then look briefly at patterns of energy supply—past, present, and potential future. I will then consider the looming challenges to energy policy and the roles of technological and institutional innovation in dealing with those challenges. Next, I will take a closer look at two of the toughest challenges—reducing dependence on oil and stabilizing atmospheric CO_2—and finally, I will address the question of whether our programs of energy research, development, demonstration, and deployment are up to the array of challenges that we face.

The Links between Energy and Human Well-being

Few people, other than energy specialists, are interested in gigajoules, kilowatt hours, and quadrillions of British thermal units—that is, interested in energy for its own sake. People are, however, interested in energy services: comfortable rooms, convenient transportation, cold beer, cooked food, sustainable employment—important things that energy helps deliver. People are also interested in the state of the economy, the state of the environment, and their personal and national security; and they are interested in energy insofar as it can be demonstrated that energy influences those values. So one needs to be clear about what those connections are in talking to the public and policy makers about energy.

Economically, affordable energy is a crucial ingredient of prosperity; and it is a necessary condition, although by no means a sufficient one, for economic development. Energy costs are typically 7 to 10 percent of the cost of living, and if those costs rise too much, the result—as we have seen from time to time—is inflation, recession, and frustration of the economic aspirations of the poor. Investments in energy supply systems worldwide are in the range of $400-$500 billion a year. They amount to approximately 15 percent of gross domestic investment in the developing countries. That is just the supply side. If one looked at investments in improving the efficiency of energy end use, it would probably double these figures. Energy accounts for about 7 percent of world trade and 25 percent of the current U.S. trade deficit.

Energy is a major contributor—often the dominant contributor—to many of the most dangerous and difficult environmental problems at the local, regional, and global levels. Providing the energy that will be needed to maintain and expand economic prosperity without undermining the environmental foundations of well-being (above all, favorable climatic conditions) is unquestionably going to be one of the biggest technological challenges of the 21st century.

There are also security problems linked to energy. Energy systems are targets and weapons for terrorists. Nuclear energy facilities, hydroelectric dams, oil refineries, and natural-gas storage are all points of potential vulnerability. These are critically important infrastructures for our society and obvious targets for terrorist activity. We are also afflicted with a considerable potential for conflict over access to the remaining supplies of inexpensive oil and gas on the planet, which are concentrated in too few places—often places of great political instability. We must worry about the links between nuclear energy technologies and nuclear weapons capabilities and how those links can be minimized. And we need to think about the potential for political tensions and upheavals resulting from energy strategy inadequacies and energy policy blunders that create or perpetuate economic or environmental impoverishment—the most fundamental and enduring causes of tension and conflict in the world in which we live and the future world into which we are moving.

Energy Supply Patterns: Past, Present, and Future

Figure 1

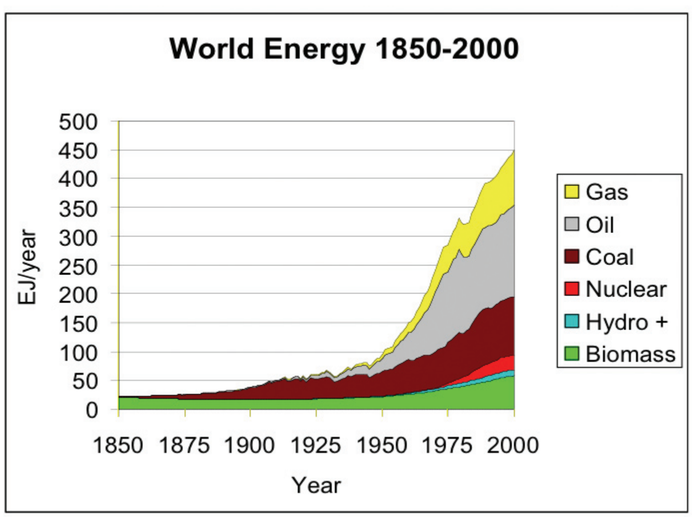


Figure 1 is a picture of primary energy supply worldwide for the last 150 years (1850–2000). Current energy use is 450 exajoules per year. The green band at the bottom shows the traditional biomass fuels, notably wood, charcoal, crop waste, and dung. These fuels are often left out of global tabulations because, for the most part, they are not exchanged in formal markets; yet they are the most important primary energy supplies for the two billion poorest people on the planet. In 1850, they were the dominant energy supplies worldwide—88 percent of world energy use in 1850 came from biomass fuels. The remaining 12 percent came from coal.

In the hundred years from 1850 to 1950, the expansion of the world energy supply was overwhelmingly driven by the expansion of coal. In the fifty years from 1950 to 2000, the rate of growth of energy use was more than twice that in the previous hundred years. (Energy use increased by a factor of 4.7 between 1950 and 2000, compared to 4.3 between 1850 and 1950.) The growth in the last fifty years was overwhelmingly driven by the expansion of oil and natural gas. In the year 2000, 78 percent of the world's energy supply came from the fossil fuels (oil, natural gas, and coal); 6 percent came from nuclear energy; 2 percent from hydropower; and, astonishingly, 13 percent of world energy supply still came from the biomass fuels. The numbers for the United States and China are given in Table I for comparison. They are both overwhelmingly dependent on fossil fuels, as is the world as a whole.

Another way to think about the distribution of energy and economic activity in the world is to divide it by income class. I have done so in Table II for the year 2000, based on purchasing-power-parity-corrected gross domestic product (GDP) per person in the various countries of the world.

Table II

ENERGY & ECONOMY BY INCOME CLASS
2000

	Poor	Transitional	Rich
POPULATION, billions	4.1	1.2	0.8
GDP, trillion $ (ppp-corrected)	11	11	23
INDUSTRIAL ENERGY, terawatts	2.9	3.2	6.3
BIOMASS ENERGY, terawatts	1.4	0.2	0.2
FOSSIL CARBON, GtC/yr	1.6	1.7	3.1
per person			
GDP, thousand $	2.7	9.2	29
TOTAL ENERGY, kilowatts	1.0	2.8	8.1
FOSSIL CARBON, tC/yr	0.4	1.4	3.9

[poor = <$5k/pers-yr, transition = $5k-20k, rich = >$20k]

I have divided the world into three economic groups: poor, transitional, and rich. Poor countries are those with less than $5,000/yr per person in purchasing-power-parity-corrected GDP, economies in transition are those with $5,000 to $20,000/yr per person, and rich countries are those with over $20,000/yr. According to this classification, 4.1 billion people in 2000 lived in poor countries, 1.2 billion in transition countries, and 800 million in the rich countries.

The rich countries, with 13 percent of the world's population, had a bit over half of the purchasing-power-parity-corrected GDP, which is about $45 trillion. The rich countries had just about half of the industrial energy use. They used a smaller fraction of the biomass energy and accounted for about half of the 6.4 gigatonnes of fossil carbon emitted to the atmosphere as CO_2.

The per capita figures at the bottom are quite striking. GDP per person in the poor countries is $2,700; in the rich countries it is more than ten times as much. Energy per person in the rich counties is about eight kilowatts, compared to one kilowatt in the poor countries. (These are the figures for total energy—not just electricity—measured as joules/year divided by seconds/yr to give watts = joules per second.)

Next, let us look at the future, focusing on what is often called the "business as usual" (BAU) scenario (see Table III), meaning we march into the future on more or less the recent trajectory. Note that BAU does not mean that nothing changes. It means things continue to change in, more or less, the pattern in which they have recently been changing. For example, population growth rates worldwide continue to fall under BAU until they reach zero—a stable population—around 2100. Economic growth continues. Improvements in energy efficiency of the economy and reductions in the carbon intensity of energy supply also continue at the recent historical rates.

What we get under this circumstance is world population increasing from about 6.1 billion in 2000 to nearly 10 billion in 2050, stabilizing around 11 billion in 2100. Aggregate economic growth is 2.5 percent per year real economic growth over the whole century worldwide. That means world economic product grows from $45 trillion in 2000 to $180 trillion in 2050 and about $500 trillion in 2100, expressed in year-2000 U.S. dollars. The energy efficiency of the world economy improves at about one percent per year. That means energy use will increase about 2.5-fold by 2050 and quadruple by 2100, giving 1850 exajoules/yr in 2100 compared to the 450 we saw in 2000. Carbon intensity of energy supply falls under BAU at about 0.2 percent per year. Carbon emissions from fossil fuel burning therefore go from over 6 billion tonnes/yr in 2000 to some 20 billion tonnes/yr in 2100. (This scenario is approximately the same as the "middle of the road" IS92a scenario developed by the Intergovernmental Panel on Climate Change (IPCC) for its mid-1990s Second Assessment.)

Table III

A "BUSINESS AS USUAL" SCENARIO TO 2100

- World population increases from 6.1 billion in 2000 to 9.8 billion in 2050, stabilizing by 2100 at about 11 billion.
- Aggregate economic growth averages 2.8% per year from 2000 to 2020 and 2.5% per year over the whole century, in real terms. World economic product, corrected for purchasing power parity, grows from about $45 trillion in 2000 to $180 trillion in 2050, and $510 trillion in 2100 (2000 US$).
- Energy intensity of economic activity falls at the long-term historical rate of 1%/yr. Energy use increases about 2.5 fold by 2050 and quadruples by 2100 (giving 1850 EJ/yr in 2100 compared to 450 EJ/yr in 2000).
- Carbon intensity of energy supply falls at 0.2%/yr. Carbon emissions from fossil-fuel burning go from a bit over 6 billion tonnes/yr in 2000 to some 20 billion tonnes/yr in 2100.

The Challenges of "Business as Usual"

Is there any reason to worry about the consequences of following this trajectory? The relevant question that first occurs to most people is: Will the world's resources of energy be sufficient to support that BAU trajectory of rising energy use? One can calculate the requirement easily by doing an integral to get the cumulative energy use in the 21st century, which would be about 113,000 exajoules, or 3,600 terawatt-years. (A terawatt-year corresponds to an energy flow rate of a terawatt maintained over a year.) The short answer to whether there is enough energy to meet this requirement is, yes. There is not going to be a lack of energy in any global sense to prevent us from staying on the BAU trajectory.

This is shown in Table IV, which summarizes approximate estimates of the world's remaining ultimately recoverable non-renewable energy resources, measured in terawatt-years.

Table IV

BAU: The answer to the resource question is YES.

REMAINING ULTIMATELY RECOVERABLE NONRENEWABLE RESOURCES (in terawatt-years)

	TWy
OIL & GAS, CONVENTIONAL	1,000
UNCONVENTIONAL OIL & GAS (excluding clathrates)	2,000
COAL	5,000
METHANE CLATHRATES	20,000
OIL SHALE	30,000
URANIUM IN LWRs	2,000
...IN LMFBRs	2,000,000
FUSION, D-T FUEL (Li limit)	140,000,000
...D_D FUEL	250,000,000,000
GEOTHERMAL STEAM	4,000
...HOT DRY ROCK	1,000,000

These are to be distinguished from reserves, which refer to how much material has already been found and measured that is economically extractable with current technology under current market conditions. Remaining ultimately recoverable resources refer, by contrast, to estimates of how much material will ever be found and be economically extractable given future technologies and future market circumstances. This is of course a difficult thing to estimate, but it is much more relevant than reserves to an assessment of how much energy is out there.

Conventional oil and gas together amount to perhaps 1,000 terawatt-years. Resources of unconventional oil and gas, excluding the methane clathrates, are about twice as large. Coal is two to three times as big as that. How much methane clathrates will ever be economically recoverable is unclear, but a middle-of-the-road figure is 20,000 terawatt-years. Oil shale is about 30,000 terawatt-years. Obviously, there is a huge amount of fossil fuel out there when one looks at these lower-grade possibilities.

Uranium, if used in light-water reactors with a once-through fuel cycle—the dominant approach today—would yield perhaps 2,000 terawatt-years. If we built liquid-metal, fast-breeder reactors, which can use uranium a hundred times more efficiently and which open up at least ten times the resources for economic exploitation because of that high fuel efficiency, we could get two million terawatt-years from fission. If we could make fusion work and make it economically attractive, it could provide 140 million terawatt-years from half of the lithium dissolved in sea water (assuming the successful fusion technology to be based on the deuterium-tritium reaction, which depends on breeding the tritium from lithium). If fusion based on the deuterium-deuterium reaction succeeded, this could supply 250 billion terawatt-years from half the deuterium in sea water.

Isolated deposits of geothermal steam, which are mined much as fossil fuels are, contain about 4,000 terawatt-years, while tapping the geothermal energy in hot dry rock, if this proved economically attractive, could yield something like a million terawatt-years. Leaving all these nonrenewable energy resources aside, moreover, renewable energy sources would also suffice if civilization chose to use these instead (Table V). Clearly, there is plenty of energy out there in an absolute sense.

Table V

BAU: Renewable energy is also enough

THE MAIN FLOW-LIMITED (RENEWABLE) RESOURCES

	TW = TWyr/yr
Sunlight reaching earth's surface	88,000
…land surface	26,000
Solar energy transferred to winds	2,000
Global biomass production	100
…of which terrestrial	60

Remember, even in 2100 BAU uses "only" 60 TW.

The question then is: Why worry about BAU? If we are not going to run out of energy, why not let the marketplace take care of how much comes from what? The fact is there are other "running out" questions that we ought to be concerned about:

- **Are we running out of cheap oil?** There are interesting arguments about how rapidly the world may be running out of cheap oil and what trouble and conflict may be encountered as the world's nations maneuver for access to the cheapest of what remains.
- **Are we running out of environment?** This question refers to the danger of running out of the capacity of the environment to absorb, without intolerable consequences, the impacts of getting energy in the ways and in the quantities that we now do it, and the ways and quantities that are forecasted under business as usual.

- **Are we running out of tolerance for inequity?** Here I refer to inequity in the distribution of energy use, its economic benefits, and its environmental costs, as suggested by the patterns shown in Table II.
- **Are we running out of money for better energy options?** There are two different ways in which it makes sense to talk about running out of money. One is in the poor countries, the very definition of which is that there isn't enough money to do all that is required. For them, the problem is simply not having the capital to build the advanced energy technologies needed for a sustainable prosperity without wrecking local, regional, and ultimately global environments. In the rich countries, we clearly have plenty of money for better energy options, but our willingness to spend it for these purposes has been very limited indeed. (I will look at this more closely later in the presentation.)
- **Are we running out of time for a smooth transition?** The characteristic time scale of the energy system is 30 to 50 years—the average operating lifetime of power plants, oil refineries, and so on. If we decide tomorrow—for reasons of climate change or oil dependence or whatever—that we want an energy system that is not 78 percent dependent on fossil fuels, using today's technologies, we will find that it cannot be changed very quickly. The capital investment in today's global energy system is $10 to 12 trillion. We cannot turn over a $12 trillion investment in 40-year-lifetime facilities overnight. If we want the power plants that are operating in the year 2050 to look substantially different from the power plants that are operating today, we'd better start thinking about it now, because the power plants that are on our drawing boards are the ones that will go into operation in 2010 or 2015, and they will still be running in 2050.
- **Are we running out of the leadership to do what is required?** (Or even to explain to the public that something must be done?) Alas, it would appear so.

Let us take a closer look at some of these concerns.

Energy and Environment

Many of the most difficult and dangerous environmental problems at every level of economic development—from the damage that the very poor do to their immediate environment and thus to themselves, to the damage that the very rich do to global environmental systems and thus to everybody—arise from the harvesting, transporting, processing, and converting of energy. Energy supply is the source of most indoor and outdoor pollution, most radioactive waste, much of the hydrocarbon and trace-metal pollution of soil and ground water, and most of the anthropogenic emissions of the greenhouse gases that are altering the global climate. As already noted, however, energy is also an indispensable ingredient of material well-being and economic development. Because the environmental characteristics of the energy resources and technologies on which we depend today can generally be changed only slowly and at considerable cost, the dilemma of the dual roles of energy in economic prosperity and environmental disruption is not a dilemma that is easily resolved.

In light of all this, I suggest that energy is the core of the environmental problem, that environment is the core of the energy problem, and that the energy-environment-economy intersection is the core of what I call the "sustainable-prosperity" problem. (I intend the term "sustainable prosperity" to include both what one ordinarily means by "sustainable development"—how to improve conditions in developing countries in ways that do not undermine the prospect of maintaining the improved conditions indefinitely—and how to further expand and sustain the prosperity already enjoyed in the industrialized countries.)

Further, I suggest that, in the long run, we will find that global climate change is the most dangerous and intractable of all of the environmental problems we face.

- It is the most dangerous because the climate affects all environmental conditions and processes and all the aspects of human well-being that depend on the environment. If you disrupt climate enough, which I believe the evidence suggests we are well on our way to doing, you disrupt everything.
- The problem is intractable because it is so deeply rooted in the overwhelming fossil-fuel dependence of the existing world energy supply system. Combustion of those fossil fuels is responsible for most of the human additions of CO_2, which is the biggest driver of anthropogenic climate change, and those emissions are too voluminous to be easily or cheaply captured and stored away from the atmosphere.

Objectives and Tensions in Energy Policy

Objectives for energy policy can usefully be aggregated under three headings: energy and the economy, energy and the environment, and energy and national security.

- **With respect to the economy:**
  a. We need to ensure the provision of basic energy services to every one.

b. We need to reliably meet the fuel and electricity needs of a growing economy.
c. We need to limit consumer costs of energy.
d. We need to limit the costs and vulnerabilities associated with overdependence on imported oil.

- **With respect to the environment:**
  a. We need to improve indoor, urban, and regional air quality.
  b. We need to limit the impacts of energy development on fragile ecosystems.
  c. We need to avoid nuclear reactor accidents and waste management mishaps.
  d. We need to limit the contribution of fossil-fuel-derived greenhouse gases to climate change risks.
- **With respect to national security:**
  a. We need to minimize the dangers of conflict over oil and gas resources.
  b. We need to reduce the vulnerability of energy systems to terrorist attacks.
  c. We need to avoid the spread of nuclear weapons from nuclear energy.
  d. We need to avoid energy blunders that perpetuate or create deprivation, which is perhaps the most deep-rooted source of conflict in the world.

Energy policy is difficult in part because these objectives are often in tension: the tension between focusing, in developing countries, on basic energy services and focusing on energy supply for the growth sectors in the economy; the tension between reducing consumer costs and protecting the environment; the tension between protecting the environment and increasing domestic oil and gas production; and the tension between increasing nuclear energy production and reducing nuclear energy risks. There are also broader tensions about where to place the emphasis in energy strategy: on the supply side or the demand side; on the role of the government or the role of the private sector; on the domestic or the international dimensions of energy problems; on the short-term or the long-term difficulties that the energy picture presents.

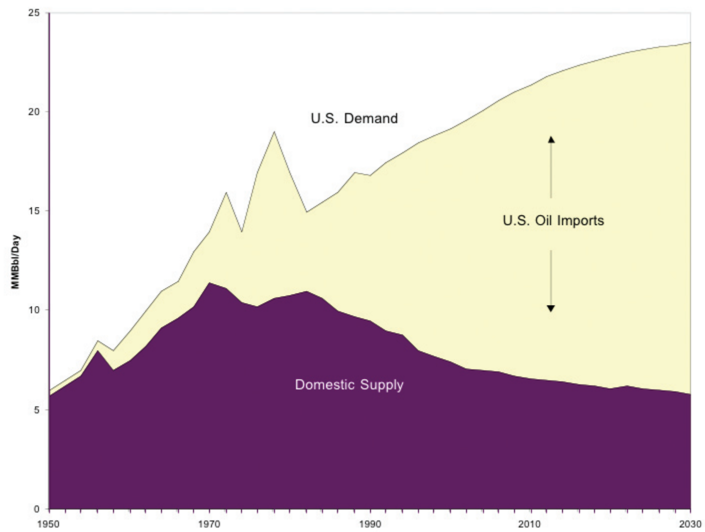
The Roles of Technological and Institutional Innovation

The toughest of the tensions between objectives can be ameliorated with the help of technological innovation. Only with improved technologies will we be able to limit oil imports without incurring excessive economic and environmental costs. Only with improved technologies will we be able to further improve urban air quality while meeting the growing demand for automobiles, especially in countries like China and India (where the latent demand for automobiles is immense). Only with improved technologies will we be able to use the world's abundant coal resources without incurring intolerable impacts on regional air quality, acid rain, and global climate. And only with improved technologies will we be able to simultaneously expand the use of nuclear energy while reducing accident and proliferation risks.

But we also need innovation in the institutional and policy domain. I suggest that only with improved institutions and policies can we provide the scale and continuity and coordination of effort in energy research and development needed to realize, in a timely way, the technological innovations just mentioned. Only with improved institutions and policies will we be able to gain the potential benefits of market competition in the electricity sector while protecting public goods (including the provision of basic energy services to the poor, the preservation of adequate system reliability, and the protection of local and regional environmental quality). Only with improved institutions and policies will we be able to ensure the rapid diffusion of cleaner and more efficient energy technologies across the least-developed countries and sectors. And only with better institutions and policies will we be able to devise and implement an equitable, adequate, and achievable cooperative framework for limiting the global emissions of greenhouse gases.

Let us take a closer look at two of the toughest challenges: reducing oil dependence and stabilizing atmospheric CO_2. Figure 2 is a picture of U.S. oil supply and demand—historical data for 1950 to 2000, plus a projection by the U.S. Energy Information Administration out to 2030. The projection shown for domestic supply does not include any contribution from the Artic National Wildlife Refuge (ANWR). The widening gap between demand and domestic supply is apparent. What could be done to reduce that? The technical potential is there to narrow the gap with both substitutes for oil and increased efficiency in oil use, but big efforts will be required in both supply side and demand side.

Figure 2



Now let us look at the magnitude of the challenge if we decided, as a global society, that we wanted to stabilize atmospheric CO_2 at or below the 550 ppm level that represents roughly a doubling of the pre-industrial concentration. How much would we need to increase the contribution of carbon-free energy to the societal energy budget in order to achieve this? An approximate calculation shows that not exceeding a doubling of pre-industrial CO_2 in the atmosphere requires that conventional fossil primary energy must not exceed 500 exajoules in 2050 and 350 exajoules in 2100. (The starting point is the 350 exajoules from conventional fossil energy being supplied in the year 2000.) One can then calculate, given BAU growth in the economy and energy supply, how much the carbon-free part of energy supply (100 exajoules in 2000) needs to grow. This carbon-free contribution can only come from nuclear energy, from renewable energy, and from advanced fossil-fuel technologies that are able to capture and sequester the carbon rather than releasing it into the atmosphere.

As shown in Table VI, the results are that under BAU (entailing 1 percent per year improvement worldwide in the energy efficiency of the economy), not exceeding a doubling of atmospheric CO_2 requires that carbon-free energy increase six fold by 2050 and 15 fold by 2100. If we can increase the rate of improvement of energy efficiency by 50 percent so that worldwide the energy intensity of economic activity falls at 1.5 percent per year instead of 1 percent per year, then the carbon goal could be achieved with a 3.5-fold increase in carbon-free energy by 2050 and an eight-fold increase by 2100. Only if we could double the rate of improvement of energy efficiency worldwide and over the whole century—from 1 to 2 percent per year—would the carbon goal be manageable, with an increase of a "mere" 3.5 fold in carbon-free energy over the 21st century.

Table VI

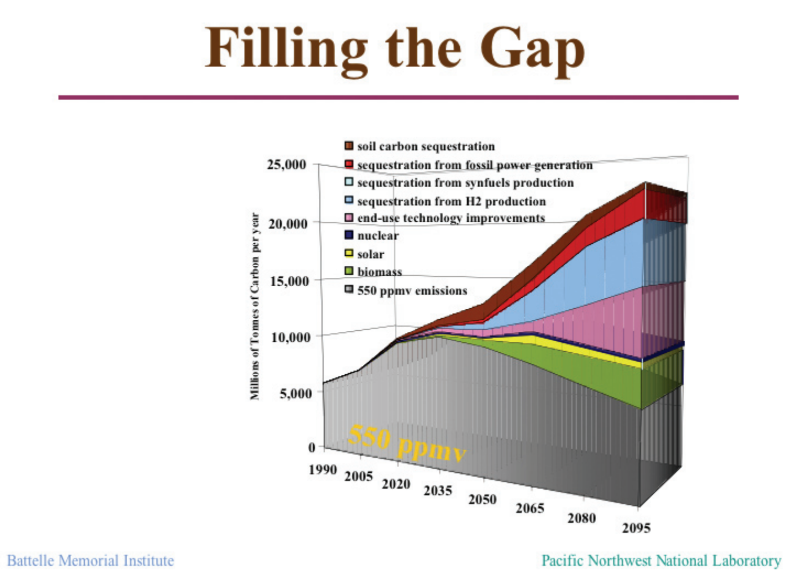
Increase in C-free energy needed to stabilize atmospheric CO_2 below 550 ppm_v

To avoid a doubling of preindustrial CO_2, conventional fossil primary energy must not exceed 500 EJ in 2050 and 350 EJ in 2100. Starting from 350 EJ of conventional fossil fuel in 2000 and BAU rates of change in world GDP and energy intensity, it follows that…

	2000	2050	2100
C-free energy under BAU	100	600	1500
...if E/GDP falls 1.5%/yr	100	350	800
...if E/GDP falls 2.0%/yr	100	180	350

Clearly, this goal of not exceeding a doubling of the pre-industrial CO_2 concentration in the atmosphere poses immense technological challenges for the energy sector, on both the supply side and the demand side. Can efficiency improvements be pushed hard enough to achieve energy-intensity reductions averaging 1.5 percent or 2 percent per year over the whole world and the whole 21st century? How much can the various carbon-free sources realistically contribute? Figure 3 is a graphical depiction from the Pacific Northwest National Lab of how the pieces of such a scenario might fit together.

Figure 3



The units are millions of metric tonnes of carbon emitted per year in CO_2, and the colored wedges are contributions to reducing emissions from the "business as usual" trajectory (top line in the figure) to the trajectory needed to stabilize CO_2 at 550 parts per million by volume (gray solid at the bottom).

Adequacy of Energy-Technology-Innovation Effort

Are our programs of energy research, development, demonstration, and deployment up to the challenges? Figure 4 is a picture of U.S. investments in energy R&D from 1973 to 1999.

Figure 4

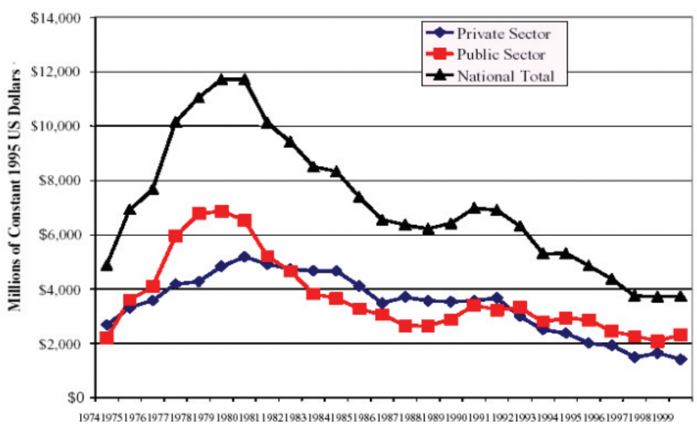


Chart 1. US national investments in energy R&D, 1974-99.

Source: World Energy Council

The conspicuous peak in the late 1970s was associated with "Project Independence," which included giant synfuels plants, heavy spending for the Clinch River Breeder Reactor, and more. Much of this was subsequently cancelled, for good reason. These giant technological projects, with the government choosing the winners, were correctly deemed not to be the best use of the public's resources.

But notice that the overall pattern of decline after 1979 occurred in both private and public sectors. The proposition that if the government did less the private sector would do more proved not to be correct.

In 1997, the President's Council of Advisors on Science and Technology (PCAST) looked at this issue at the request of President Clinton and made a number of recommendations (I had the honor of chairing that study). The PCAST panel recommended that Department of Energy (DOE) spending for applied energy technology R&D—spending on fission, fusion, fossil, renewables, and end-use efficiency combined—should be ramped up from $1.3 billion per year in FY1997 and FY1999 to about $2.4 billion in 2003, with about 80 percent of the increases to go to efficiency and renewables. PCAST also recommended some cuts—including for short-term, coal technology R&D, which we judged would better be done by industry. The PCAST panel had 21 members; they came from all across the industrial, academic, and non-government organizations (NGO) sectors and had backgrounds in fossil, nuclear, renewable, and end-use-efficiency technologies. Notwithstanding this diversity, their recommendations were unanimous.

In addition to the recommendation to increase applied energy technology R&D overall, the PCAST panel recommended expanding research in basic energy sciences, as well as improving internal communication and coordination within the DOE among the different applied R&D divisions and between those divisions and the basic energy sciences effort. (Ernie Moniz, who was the Undersecretary of Energy at the time, took this last advice and instituted a variety of measures to improve internal communication and coordination in DOE's energy R&D efforts.) PCAST also suggested that the government should think about a commercialization strategy that would complement public investments in R&D, emphasizing public/private partnerships and limiting in magnitude and duration the public resources invested. And it proposed that the United States increase its participation in international cooperation on energy research, development, demonstration, and commercialization—especially with developing countries.

The Clinton administration requested about two thirds of what PCAST recommended, and the Congress appropriated 60 percent of what the administration requested—hence 40 percent of the PCAST recommendations (Table VII). Unfortunately, the gap between what PCAST recommended, what the administration requested, and what Congress appropriated got wider in subsequent years. There followed a 1999 PCAST study of federal support for international cooperation on energy technology and innovation. Neal Lane was a major force in shaping, guiding, and pushing the 1999 study, as was Rosina Bierbaum, then the associate director for Environment of the Office of Science and Technology Policy (OSTP), under Neal. That study recommended substantial increases in the funding for international energy cooperation. It made recommendations on the foundations of innovation and cooperation; on cooperation in specific areas of energy and use efficiency; on cooperation in specific areas of advanced energy supply; and on improvements in the management of international cooperation in energy research development, demonstration, and deployment.

Table VII

Federal Energy Technology R&D: Congressional Appropriations, Administration Requests, PCAST Recommendations (10^6 as-spent-$)

	effic	renew	foss	nucl fiss	nucl fusn	total
FY98 appropriation	437	272	356	7	223	1295
FY99 appropriation	503	336	384	30	222	1475
Admin request	594	372	383	44	228	1621
PCAST reccmdtn	615	475	379	66	250	1785
FY00 appropriation	552	310	404	40	250	1556
Admin request	655	398	340	41	222	1656
PCAST reccmdtn	690	585	406	86	270	2037
FY01 appropriation	600	375	433	59	255	1722
Admin request	630	410	385	52	247	1724
PCAST reccmdtn	770	620	433	101	290	2214
FY02 appropriation	617	386	446	68	248	1765
Admin request	475	237	333	39	255	1339
PCAST reccmdtn	820	636	437	116	320	2329
FY03 appropriation	628	422	475	75	250	1850
Admin request	561	408	483	89	257	1798
PCAST reccmdtn	880	652	433	119	328	2412

The 1999 recommendations fared less well than those of 1997 in the budget process, however. Of the initial increment of $250 million recommended by PCAST, the administration asked Congress for $100 million—a figure that emerged from the interagency task force that was created under Neal and Rosina to coordinate those budgets. But out of that $100 million request, Congress appropriated a mere $8.5 million. This reflects the well-known reality that it is harder to persuade Congress to fund international cooperation than it is to persuade it to fund domestic R&D.

What, then, has the Bush administration done? In May 2001, the Cheney commission report on U.S. energy policy actually said a number of very sensible things. It recommended a national priority for improving energy efficiency, including a permanent extension of the existing R&D tax credits; tax credits for fuel-cell vehicles and advanced bus propulsion; tax credits and exemptions to support renewables; a commitment to advancing clean coal technologies, next generation nuclear fission power plants, nuclear fusion, and hydrogen; and expanded support for international collaboration on energy R&D. Perhaps the biggest shortcoming in the Cheney commission's report was that there were so many recommendations and so little indication of priorities that it was hard to tell what the administration really proposed to do.

Another shortcoming of the Cheney energy policy document was that it barely mentioned climate change as a part of the energy policy challenge faced by this country and the world. This is consistent, unfortunately, with the administration's rejection of the Kyoto protocol on grounds that implementing it would hurt the U.S. economy. (One can as easily argue that not addressing the climate problem will hurt the economy—and much else.) And, in the end, the administration actually reduced the budgets for R&D on energy efficiency and renewable energy technologies. It also offered, as an alternative to Kyoto, a voluntary emissions reduction target for the United States that amounts to reducing the economy's greenhouse gas emissions intensity—the ratio of emissions to real GDP—by no more in the next ten years than the amount by which this ratio was reduced in the last ten years under BAU.

This is not enough. We will need to do a lot better.

ENERGY AND THE HUMAN CONDITION

Discussion

Question: You didn't talk about either taxes or some sort of cap-and-trade regime.Particularly if that were made revenue neutral by using such revenues to reduce payroll taxes or something like that, do you think that would stand a chance?

Holdren: I do believe that an emissions cap on carbon, implemented through tradable permits with a safety valve (so you could control what the maximum economic impact would be)—and with the emissions cap ratcheting downwards over time and the safety valve ratcheting up—would be effective as an approach to reducing greenhouse gas emissions and would be politically more acceptable than a carbon tax. As I think we all know, the "T" word has been a forbidden word in Washington for some time, not only in the current administration but also in the previous one. But a cap-and-trade scheme, which has the same effect as a tax, does have a chance politically and is probably the direction in which the country will eventually move. I would guess that when this happens, it will begin with the safety valve around $20-$30 per ton of carbon. Although such figures are lower than what will probably be required eventually to do the whole job, I think that, once industry accepts that a significant charge on carbon emissions is here to stay, there will be a great deal of innovation in the direction of finding ways to reduce those emissions more cheaply than most people think is possible today.

Question: You have talked about the roles of technology and government in the issues of energy, environment, and security. I wonder what you think about the role of the consumer.

Holdren: First of all, the role of the consumer is paramount when one enters the arena of end-use efficiency. You will have noticed in my presentation that there is tremendous leverage in improving the efficiency in which energy is used throughout the economy—in buildings, vehicles, and manufacturing processes. In all those sectors, consumers—be they firms, individual home owners, or automobile buyers—have got to make sensible decisions. One of the key barriers to making sensible decisions is the information and education available to consumers, so that they understand the energy and energy-cost implications of choosing a particular new car or new refrigerator. The Energy Star program has made great strides in improving the understanding of consumers about what they are getting in energy terms when they buy an appliance. There are lots of ways to get similar information out there in relation to other consumer choices, and we will have to do a lot more of this. After all, if you want to get energy end-use efficiency right, billions of consumers have to make good decisions.

Question: I was very taken by your explanation that the bump in the R&D in the 1970s is largely due to the white elephant technology demonstrations. I was wondering if that is really all of that peak, or have we really cut down on the sensible energy R&D as well.

Holdren: If one looks at a more disaggregated picture of the historical trends in energy R&D, one finds that the big demonstration projects were a part of the peak and decline, but something else that happened in the 1970s in response to the oil-price shocks was an immense diversification of government energy R&D. Prior to the oil price shocks, the great bulk of R&D was nuclear fission and fusion, plus a bit of coal research. There was very little being spent on renewables or efficiency or a wider diversity of fossil fuel technologies. The 1970s brought big expansions in R&D on energy-end-use efficiency, renewables, and advanced fossil fuel technologies, and much of that diversity was preserved into the 1980s. Tracing the curves all the way into the mid-1990s shows that the absolute level of spending on energy R&D in inflation-corrected dollars was about what it was in the mid-1960s, but the distribution was completely different—a nearly uniform distribution across fossil, fusion, efficiency, and renewables, and much lower spending than before on fission.

Question: If you follow the total expenditures of U.S. R&D of energy from the 1970s to 2000, have you compared it to total world expenditures?

Holdren: Yes, those figures are also available. First of all, most of the energy R&D in the world is done in the Organization for Economic Cooperation and Development (OECD) countries. And the OECD pattern as a whole is quite similar to that in the United States. In real terms, expenditures on energy R&D in every OECD country except Japan have been declining on the whole over the last 20 years. Japan's energy R&D has gone up both in absolute terms and as a percentage of its gross national product. Japan is now spending more than the United States on energy R&D in absolute terms and much more in relation to the size of its economy. But everybody else has been on a downward trend.

ENERGY AND THE ENVIRONMENT: SCIENCE PANEL

Modeling Future Climate Change

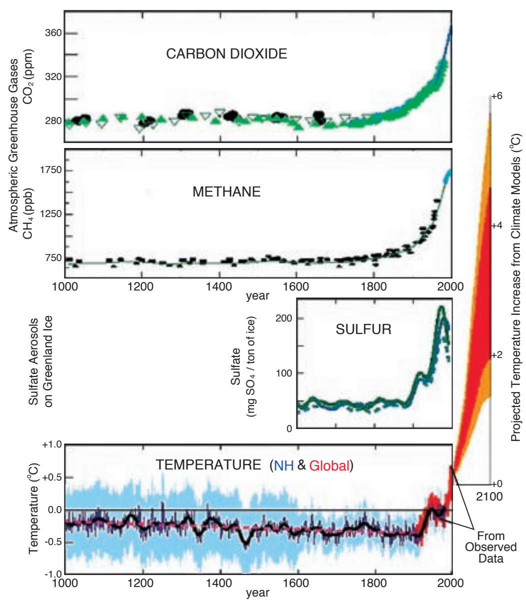
Warren Washington

I just want to mention one thing before I start my formal talk. In my early tenure on the National Science Board (NSB), I chaired the committee that looked at the second proposal criteria for the National Science Foundation (NSF). The first criteria is scientific excellence. This second criteria took into account the broader impacts of the proposed research. I worked with Neal Lane, the NSF director; the rest of the NSF management, and the Board to get the second criteria approved. I think my talk will be an excellent example of societal relevant research that has broader impacts.

I have several questions to try to answer. Can climate models help us understand climate change? I believe the answer is, yes. Can we verify climate models with observations? We are doing that, though there are still many difficulties in being able to see if our models are doing the right things. But on the whole, the models are agreeing well with observations. We have enormous amounts of historical in situ and satellite data to compare with our models. Why do model projections of future climate change differ? I will get into that in a little bit, but I can tell you that we are working with our colleagues both in the United States and internationally to sort out why computer models give different projections of future climate change.

Figure 1 shows the changes in CO_2 atmospheric concentration from a thousand years ago to the present. You can see the rapid CO_2 increase in the last part of the 20th century. The CO_2 for these measurements was found in ice cores taken from the large ice sheets of Greenland and Antarctica. The gas was trapped in air bubbles during past snowfalls. In the same ice cores are the other greenhouse gases of methane and nitrous oxide. At the bottom of the graph is shown the surface air temperatures over the last thousand years. During most recent times we have used worldwide direct measurement of temperature. Before 1860 or so, we used tree rings and coral sediments proxy data. The proxy data is calibrated by using the instrumental record for establishing correlations. This figure shows that the period in the last 30 to 50 years is really unusually warm. There was an article published just a few weeks ago showing that this temperature record has been extended back to 2,000 years, so we have an excellent indication that the late 20th century warming is remarkably different. On the far right side of the figure are future projections of surface air temperature from many climate models. Note that there is an enormous spread of projections. The world community is trying to find out why some models are more or less sensitive to increasing greenhouse gases. In spite of the uncertainty, it is clear that the climate will be warming significantly. Figure 1 also shows the sulfate aerosol concentrations with time. In the latter part of the century the concentrations have decreased due to emission controls on power plants. These aerosols act to regionally cool the climate system, but their impact is much less than the increase of greenhouse gases.

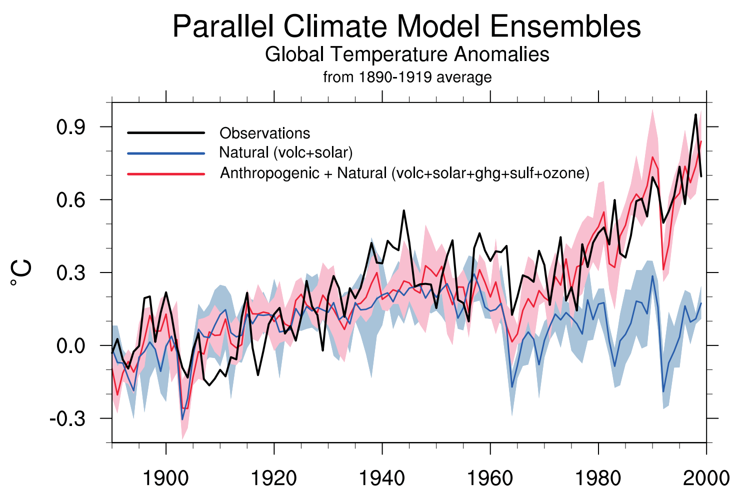
Figure 1



Essentially all climate models are showing that there is substantial warming that is likely to take place between now and the year 2100. The projected sea ice and snow distributions dramatically shrink in terms of area as well as thickness. I will not go into the details of what is in a contemporary climate model, but it basically includes atmosphere, oceans, mountains, sea ice, clouds, complicated radiation, solar changes, land cover, and vegetation. Our present-day climate models simulate virtually all of the principal climate features such as wind and temperature structure, precipitation zones, monsoons, and El Niño events. I have been in the field for over 40 years and I have witnessed the impressive progress being made in climate modeling. If you look at individual features such as storm systems, the models are quite realistic when compared to observations. I am not going to show it here, but the scientists who have been using Japan's Earth Simulator, which is the world's fastest computer, have found with a very high resolution (10 km) global model that realistic hurricanes can be produced. High resolution ocean and sea ice models also show very realistic small-scale features, so we know we are on the right track.

I do not need to tell you that there has been a big controversy about whether man is changing the climate system. Are changes that we are seeing only natural variations in the climate system? In Figure 2, I show observations and model simulations from 1870 to the present. The natural forcing of the climate system are volcanic and solar variations that we can include in our model simulations.

Figure 2



The dark blue line is the mean of five ensemble simulations, and the range of the ensemble members is the light shaded blue. Note the natural forcing simulations explain the early part of the 20th century temperature change. If anthropogenic increase in greenhouse gases and sulfate aerosols are added to the natural forcing simulations, the same pattern as the observed is reproduced. The solar forcing seems to be the predominant factor in the early part of the century and in the latter part the leading factor is the increasing greenhouse gases. The sulfate aerosols have a smaller cooling effect. It is possible to identify individual volcanoes. For example, the 1991 Pinatubo eruption is well simulated and it compares favorably with the observed short term cooling.

I would like to quote from the Intergovernmental Panel on Climate Change (IPCC): "An increasing body of observations gives a collective picture of a warming world and other changes in the climate system." This assessment involved hundreds of scientists. The average global temperature has increased in the 20th century by 0.6°C. The last decade of the 20th century was the warmest decade in the past millennium. I would like to point out that September in this last year was the warmest on record, so we are still seeing extremes being established. The snow cover, glaciers, and sea ice amounts have decreased. Sea level has risen and the ocean heat content has increased. All of these changes are consistent with model simulations and they are strong evidence of global warming.

The future climate modeling research priorities include understanding why models give different projections of future climate change and lowering uncertainties such as the role of atmospheric aerosols. We are starting to combine biogeochemistry into our models—carbon cycles, sulfate cycles, nitrogen cycles. I anticipate that these additional aspects of the climate system will become a standard part of Earth system models. Because our model has limited resolution, we cannot provide detailed information on regional climate change, which is what the public and policymakers want to know. As we acquire more powerful supercomputer systems we will be able to provide significantly improved regional predictions of climate change. However, we still need to improve our treatment of clouds, land cover, aerosols, and other climate processes. One of the reasons that models provide different sensitivities to increased greenhouse gases is that, in some models, the clouds become thicker, which causes a cooling effect because less solar radiation reaches the ground. This is a negative feedback. In other models, when the clouds increase, they more effectively trap infrared radiation in the lower atmosphere, which warms the Earth's surface. Through careful use of observational data, it is hoped that we can sort out the right answer and improve our models. Such improvements will make the model predictions more consistent.

We are rapidly improving hydrological aspects of our models. The reason for this is the increasing concern of whether we have adequate water resources, especially in the Western United States. As the climate changes, there will be many impacts on ecological systems.

Mitigation versus adaptation: I think that both are likely to be needed in the future. Climate models can provide information of the various options and provide insights about whether and how to geoengineer the climate system. That may seem like an obscene word to use—geoengineering—but we are already changing the climate system, and if we are going to be changing it, we probably need to think about not only the ethical aspects of that, but also how we should change it. Near-term climate change is inevitable. We need to think about policies that will yield minimal future impacts. A related question is: When do we get serious about geoengineering? As you recall from my earlier remarks, the global average temperature has warmed 0.6°C over the last century. What happens if it warms one degree per decade? I would imagine at that point the peoples of the world would get very serious about climate change and steps would have to be taken.

I think that climate models can aid the policy debate by providing quantitative information.

ENERGY AND THE ENVIRONMENT: SCIENCE PANEL

Uncertainties: How Little Do We Really Understand?

Michael C. MacCracken

I usually present talks on what is known. This time I was asked to talk about what we do not know, and maybe I should stop because we know so much. Warren Washington mentioned the assessment of the IPCC, and it is really an amazing way to summarize what is understood and not understood about climate change. It is an effort that involves on order of 150 countries; the IPPC recommends authors on aspects of climate science, on climate impacts, on ecological impacts, and on adaptation and mitigation issues. They go through a multi-year process involving extensive review by the expert community and that includes the scientific and industrial communities. There is an effort to pull all of our understanding together and then it is published in a report many inches high.

But they also produce something that is very important and that has been somewhat controversial. The *Summary for Policymakers* is an attempt to take those scientific findings and try to summarize them in terminology that policymakers can understand. This effort is sometimes criticized because of concerns about scientists getting together with policymakers to agree on the final wording. However, I believe the situation compares to a patient going to a doctor and the two coming to agreement about the significance of the patient's cancer. The doctor could give the patient the studies from the National Institutes of Health (NIH) and say, "You figure it out," or the two could have a dialogue about what the studies mean for the patient's case. In that dialogue, the doctor would likely be asked to switch from the hypothesis-testing analysis of statistical significance to a relative-likelihood or risk paradigm that weighs which medical treatment is the better choice. We all have to deal with the situation we face, and we face a changing climate.

What is truly amazing about the IPCC process is that it has led, on three occasions since 1990, to 150 countries unanimously agreeing to its findings. That is truly amazing on such a difficult issue. The way the IPCC achieves this is that they make the range of what could happen so broad that it includes the full range of expert opinion. It is for this reason that the estimates of warming in 2100 range from 1.4 to 5.8°C. Because scientists do not like to be wrong, they are going to choose ranges that are so big that they can encompass the full range of climate sensitivities and emissions scenarios. But when it comes to considering policy steps, the broad range, which has led to virtually unanimous international support, is criticized because the likely outcome is considered so uncertain. So treating uncertainty is a very difficult thing to do.

All scientists do not agree with all aspects of the IPCC findings, but we come pretty close. Most of the countries have been very positive about the process. They believe in the process that has been used and they largely accept the scientific findings—and that is what has been happening basically everywhere in the world except recently in the United States.

I do not know how many of you watched the debate on the McCain-Lieberman bill this past Wednesday night and Thursday morning (October 29-30, 2003), but it was a very distressing manifestation, in my view, of the misrepresentation of what is and is not understood and what the IPCC's scientific findings are. I think unfortunately, that some of those in the U.S. Senate are still debating whether climate change is occurring. While the scientific community does debate about how big climate change has been and how fast it will be changing, some of those in the Senate were debating about whether climate change was even occurring. There were a number of objections to the IPCC's consensus process by individual Senators, each holding up an individual paper and saying that it shifted the whole pyramid of knowledge that the scientific community has built.

I think this has all been very unfortunate. I think there are some real problems about how one deals with the issue of uncertainties in the public arena. What we hear about in the media, for example, is that the changes in surface temperature measured by surface instruments and the changes in tropospheric temperatures observed by satellites do not match. It turns out that when scientists look very carefully, they find that some adjustments must be made. Because of this, the National Academy of Sciences recommended that a second group look at and figure out how to convert radiances from the atmosphere in the microwave domain into estimates of tropospheric temperature. When this was done, the second group got a different answer from the first group. This occurred because there was not one instrument making all of the measurements, but 10 or 12 instruments that were used over a 20-year period. This means intercalibration must be done; but, depending on how it is done, a completely different answer could result.

There are other issues that are often mentioned by IPCC's critics—and Warren Washington covered one in responding to the question about whether the change relative to the climate of the last thousand years is real, or whether the Earth is recovering from the Little Ice Age and naturally returning to an earlier time of warmth known as the "Medieval warming." There has recently been a huge amount of traffic on the Internet about some indications of problems with the graphs that Warren Washington was showing. Basically, two individuals in Canada, neither of whom has any expertise in paleoclimatology, have tried to reproduce the analysis cited by the IPCC and they have come out with different results. They then published their article in a small U.K. journal that likes to publish controversial information, often without going through a really proper peer review. This article got widely publicized because there were a number of moneyed interests pushing the findings, making all this skeptic information widely available and generating a lot of press attention.

So there are a number of criticisms that have been raised. Warren Washington talked about the 20th century warming and that we are coming to understand why it occurred. However, there remain a number of uncertainties about the warming that are being discussed, including asking, is it real? We do not have perfect information with which to resolve this. The atmosphere is a chaotic system, climate is chaotic, and so model simulations are not going to match the past record perfectly, but there seems to be a desire to have a perfect result in that regard.

That is where the media and the congressional debates are. It is really unfortunate, because there is an entirely different set of uncertainties that are the true uncertainties we face in this issue. One is what is going to happen in the next hundred years or more in terms of what we put in the atmosphere—the aerosols, the greenhouse gases—and the land cover changes that we cause. All these things have the potential to change the climate. We have to generate some scenarios about these and figure out what might happen in the future. Not surprisingly, it turns out that scenarios are controversial.

Some in this administration do not even like the idea of scenarios; they just want a single indication of what future conditions will be. However, climate forecasting is a very difficult challenge. Typically, the question is: What is going to happen in the next hundred years? Not only does the answer depend on trends in population and technology and other things, but there is also the issue of the climate response and feedbacks. Warren Washington mentioned some of these feedbacks—the cloud radiation feedback is a very important one. I think what is absolutely fascinating though—and Warren referred to the new results from the new Japanese model—is how realistic model results are starting to look, and how much better they represent what is happening when the finer resolution models are used and are run on these very fast computers. It has been really unfortunate because the United States is lagging behind, despite all the efforts going on in some of our laboratories, in trying to really invest in computer resources for climate change. We are trying to catch up because it is really a shame that there is an uncertainty created by a lack of investment in money to provide the resources, rather than an uncertainty resulting from limited understanding of the underlying science.

There are a couple of additional uncertainties that are really important. One of them has to do with trying to figure out how the likelihood, frequency, location, and intensity of unusual events are going to change. What is going to happen to the frequency and intensity of rain? We already have some trends over the 20th century indicating that heavy rains are increasing in amount. In fact, there is a really interesting simulation that has been done with the national hurricane model, which was developed at the Geophysical Fluid Dynamics Lab. The model was run to study typhoons in the Pacific. When the surface temperature was increased by two degrees, the six-hour integral of maximum precipitation coming out of the tropical storms increased by an average of over 25 percent. Was it not here in Houston where the tropical storm dumped 30 inches of rain? What if you have to deal with 40 inches?

What climate warming does is put more moisture in the atmosphere, and because this happens, there is more latent energy (i.e., energy released as a result of the condensation of water vapor into rain) that is capable of intensifying storms. There is a lot of potential for things to happen as a result. The Canadian model was run and the return periods for particular extreme events were examined. In some of their model simulations, what is now a 100-year storm, which is typically the standard for how community infrastructure is designed, happens every thirty years. If you are going to design a community so that you only have to replace that bridge every hundred years and deal with other problems of such an extreme event, maybe the community will be fine. But if a community starts getting flooded every thirty years, it is not just the economic effects, but also the psychological effects, that are important.

Sea level rise is another area where there is an important uncertainty. It was not talked about much by Warren Washington, but it is pretty clear that a consequence of warming the world will be the melting of mountain glaciers. We have seen the early signs in glaciers all over the world. In addition, as the ocean water warms, it expands and takes up additional space. If you measure how much sea level has gone up over the last hundred years, it is about 15 to 20 centimeters. This amplified rate started to become evident in the mid-19th century, and the rate seems to be accelerating at the end of the 20th century.

IPCC's projection for sea level rise over the next hundred years spans the range from about 10 to 90 centimeters. The low end is so low because we may be very lucky and get increased precipitation over some of the big ice sheets in Greenland and Antarctica, thereby taking water out of the ocean and putting it up there. The high end of the range results if substantial melting of Greenland and West Antarctica gets started. Greenland and West Antarctica each have about six meters, 20 feet or so, of sea level equivalent tied up as ice. IPCC made an estimate that if there is a 3°C warming, this would start Greenland on a melting scenario that will probably take 1,000 years to raise sea level up 20 feet. That is even before one considers the influence of West Antarctica. What is the elevation of Houston? Six feet? There is a whole host of issues about what would happen were sea level rise to significantly accelerate. New Orleans has sunk, but it is protecting itself with levees. But if the region experiences some of the intense storms that have been projected, and depends even more on the levees, the resulting stress on the levees is going to be very hard to deal with.

It is not just sea level rise that is an issue in our country. The IPCC suggests that the impacts will be bigger in developing countries than in developed countries. After all, in developed countries we have a tremendous amount of infrastructure. One of the studies done as part of the national assessment looked at what would happen to the metro East Coast area. They asked, what if a category 3 hurricane came up to New York harbor at high tide? Hurricanes used to be going up the East Coast, if one goes back to the records of the 1940s and 1950s (this has not been occurring recently for reasons relating to apparently natural variations of the climate that we think we have an idea about). What the study found was that the storm surge height in New York harbor was likely to be 20 feet or more. The subways are protected to eight feet. New York City has had storms that have pushed sea level up by nearly seven feet! We have tremendous infrastructure at risk in this country, and it is going to take a long time to change it—not just the energy system infrastructure that John Holdren was talking about but the coastal infrastructure.

So there is a huge issue about projected increases in sea level. Regarding potential uncertainties in the estimates, it is interesting what IPCC said in its projections for the 21st century. It said that there would be no sea level rise due to the melting of Antarctica during the 21st century. But Antarctica has been melting for the last several thousand years. We know that if it gets much warmer, it is going to melt. But in this one century, the IPCC is saying, it will not warm enough for melting to begin. It is rather a conservative projection—their estimates have gotten a lot of U.S. glaciologists upset because of the possible underestimate of future sea level rise.

There are a host of other important uncertainties to be concerned about—the range of impacts on the environment is another example. But I think what I want to say in conclusion is that there is all this public focus on these little details and in getting all the little nuances of what happened during the 20th century right, and there is hardly any discussion going on about the really major uncertainties that are present and the risks that we face. Decision makers are always making decisions under uncertainty. We cannot expect to have perfect knowledge. This lays out before us a really hard problem to deal with, but we really have to give it a try.

ENERGY AND THE ENVIRONMENT: SCIENCE PANEL

A Matter of Degrees

Rosina Bierbaum

My job is to talk about impacts. That is the "So what?" question related to climate change. The answer to the "So what?" question will in fact be, "A matter of degrees." "Degrees" is meant in three ways: First, certainly it is a matter of degrees in terms of ultimate temperature change. That is the area most of the climate science enterprise has been devoted to over the last several decades, working on the physical and the chemical aspects of climate change. But second, I would also argue that climate impacts will be a matter of degrees in terms of the summation of environmental insults that result from climate change in concert with other stressors such as air pollution, invasive species, habitat degradation, biodiversity loss, etc. Climate change will not occur in isolation and understanding how all of these problems interact will, in fact, determine what the composite impact is. Third, the impact of climate change will also be a matter of degrees in terms of latitude and longitude—where one lives on the planet—because that determines both your vulnerability and, ultimately, your capacity to cope with climate change.

This table compiles some of the impacts that have already occurred as a result of the changing climate.

Table I

Observed Changes	Examples	Extent in Space and Time
Physical Processes	• 10% decline in sea-ice extent and 40% decrease in thickness • Roads and buildings collapse as permafrost thaws	• Arctic since 1950's • Alaska
Hydrology	• Mountain glaciers recede • Later freeze/earlier thaw in lake and river ice • 5% to 10% rainfall increase	• All continents over past century • Northern Hemisphere over past century • Northern Hemisphere over past 100 years
Vegetation	• Earlier blooming dates from botanic gardens • 10% increase in photosynthesis	• Europe/US • Northern high latitudes since 1981
Animal Species	• Poleward and elevation shifts in butterfly species • Amphibian declines • Shifts in timing of bird reproduction	• North America, UK, and Europe • Costa Rica • US, UK, and Europe
Pest Species	• Spruce budworm damage to forests, northward expansion • Spruce bark beetle kills trees over large areas	• Canada and US since 1950's • Alaska, especially Kenai Peninsula, in 1990's

The IPCC report, referenced earlier, concludes that some impacts are taking place today, that some biological systems may be irreversibly damaged in the future, and—very important in terms of equity—that those countries with the least capacity to adapt may be in fact the most vulnerable. On the left side of the table are listed some of the physical changes that have been observed—a 10 percent decline in sea ice and a 40 percent decrease in thickness. Permafrost is also melting. Alaska has been much in the news, with temperatures increasing up to about 7°F over the last century. Mountain glaciers are receding worldwide such that by 2030 there will be no glaciers in Glacier National Park, which for us may be an aesthetic loss, having a park "formerly known as Glacier," but I would argue that for cities in the world that depend on mountain glaciers for drinking water—such as parts of Peru—this loss will in fact create a serious human problem.

Under the category of vegetation, studies of some 75 reference gardens around the world have revealed that spring is arriving about a week earlier and fall, five to seven days later than several decades ago. Those of you from Washington, D.C., know that we finally bit the bullet and declared that the cherry blossom festival should be held a little earlier because, so may years running, the festival occurred long after the cherry blossoms had bloomed and dropped.

Under the category of animal species, there are some 400 examples of ranges shifting in the direction expected as climate changes—that is, either north in latitude or higher in altitude. Principally, these are bird, butterfly, and amphibian species. There have been explosive pest outbreaks, such as the well-documented case in the Kenai Peninsula in Alaska where 10 million acres of forest are now dead due to infestations of spruce bark beetles. Historically, damage from these insects would be contained by the cold Alaskan winters; recently, however, temperatures have not been cold enough to kill these pests.

What does the future portend? Temperatures will increase another 1.4 to 5.8°C over the next hundred years, which is a frightening pace to ecologists. That rate is about 4 to 10 times the rate of temperature changes that ecosystems have responded to over the last 10,000 years, the time in which humanity flowered, if you will. The future is, therefore, outside human kind. Can ecosystems and the parts of them keep up with this changing pace? That's a question much in need of an answer. The change in temperature, the amplification in the hydrological cycle that will increase precipitation, and the increase in sea-level rise will change the ideal range for just about all plants, animals, pests, and diseased species. To the extent that we have studied impacts, the focus has been mainly on changes resulting from a doubled CO_2 world (that is, when concentrations in the atmosphere are twice pre-industrial levels). Yet, as you have heard, we are headed towards a tripled or quadrupled concentration level under "business as usual." We have not examined ecologically what this might mean and have very little understanding of what devils may be in the details of such changes. If I had a "John Holdren" unit of time to speak, I would take you through projected impacts, sector by sector, such as they have been identified. However, in the spirit of this conference—bridging the gap between science and society—and in recognition of how little we know, let me suggest five areas where enhanced research is greatly needed.

Let me start with "Regional Impacts." We must begin to get a handle on how climate change will manifest itself in a region. Nobody lives in the "global average climate," so knowing the global average climate change does not help translate what sort of "pain" or "gain" you may feel in your "place."

Figure 1

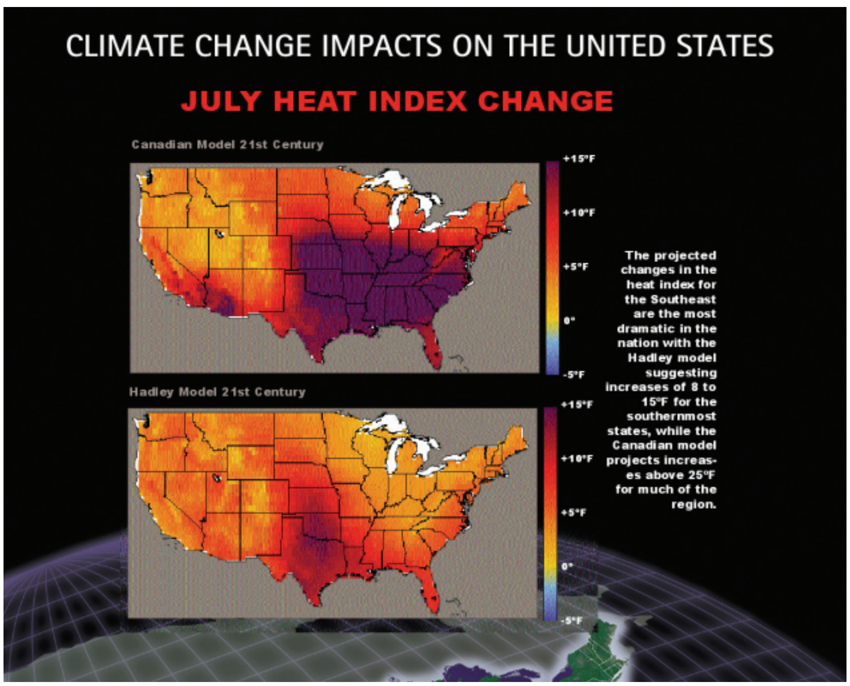
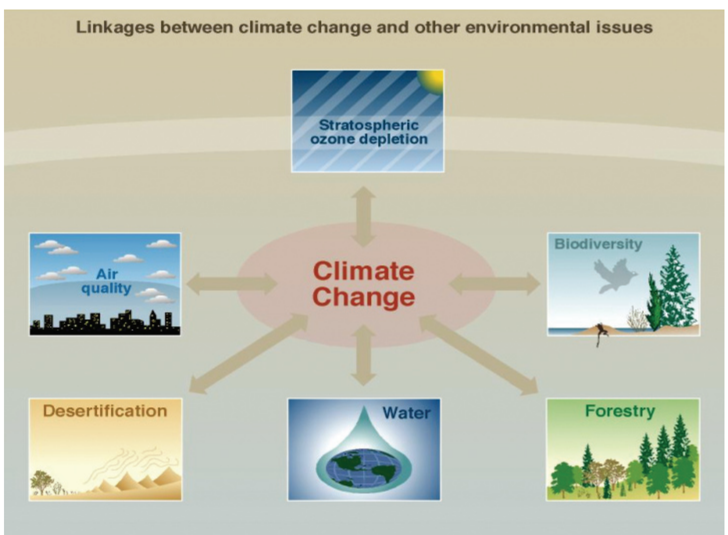


Figure 1 shows you the projected heat index in July, based on the Canadian and Hadley climate models, which were used in the U.S. National Assessment conducted under congressional mandate. You see that, over the next century, warming is expected to occur throughout the lower 48 states, but there is quite a bit of regional variability. The deep purple shows something akin to an increase in the heat index of 15°F—that is, by the end of the century, a July day could feel, on average, 15°F than a July day today. Clearly, we need to refine these kinds of regional estimates. But if you are thinking of a place to move, Texas might not be the best choice, heat-wise! On a more serious note though, the heat index is a very important health issue. This past summer in Europe (2003), thousands died in the intense and persistent heat. The Chicago heat wave a few years ago killed somewhere between 400 and 700 people. That event becomes much more probable as climate changes are no longer a once-in-every-150-years event, but occur every 25 years. In 2003, there are many other regional impacts of concern. For example, the range of sugar maples may move north, and these trees could disappear from New England. We can all imagine what that would mean in terms of fall foliage, tourism, and pancakes. If we think about the forests in the Southeast, the very lucrative loblolly pine stands are projected to decrease significantly in the future. So regional impacts are very important to begin to understand and can mean fundamental changes in our quality of life.

The second area needing additional research is “Interactions with other environmental issues,” Fugure 2. Climate change is not occurring in isolation but in concert with other stresses.

Figure 2

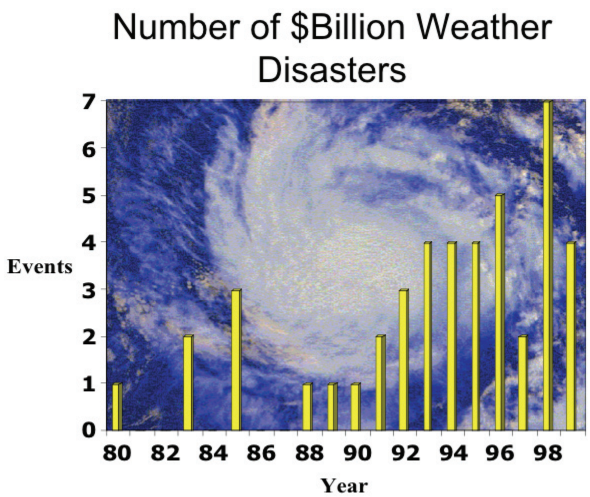


A warmer world could lead to increased air quality concerns. Some regions may not be able to meet their air quality goals as the warmer temperatures enhance smog formation. A warmer world could be a greener world and augment forest growth, which would somewhat slow carbon buildup in the atmosphere since carbon is stored in trees. But a warmer climate may also enhance pest outbreaks and exacerbate dry conditions contributing to forest fires, which can lead to pulses of carbon into the atmosphere—a negative impact.

Biodiversity preservation is also a key concern—the world is spending several hundred million dollars a year to sustain biodiversity "hotspots" around the world. But, it is not clear that where these species currently live will still be tenable ranges as climate change proceeds. In order to maximize efficiency and effectiveness of mitigation and adaptation measures for climate change, it is imperative we understand the interrelationships with other environmental stresses.

The third area needing research is "Extreme events" and their consequences. Figure 3 shows the number of billion-dollar weather disasters over the last 20 years. They have been increasing; most of this is obviously not due to climate change but rather because of the continued colonization of the fragile coastlines of the world, where flooding and wind damage is most frequent.

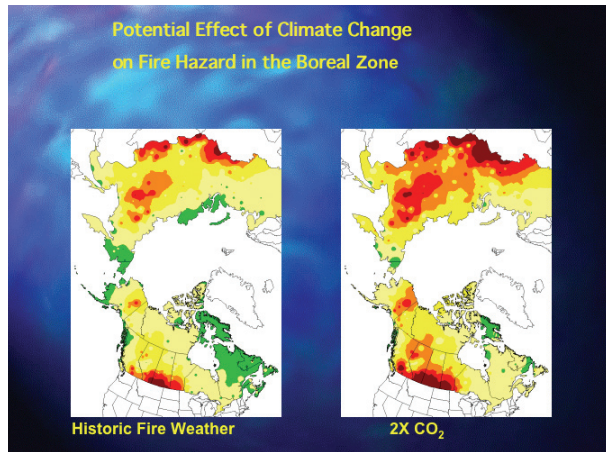
Figure 3



However, as the hydrological cycle speeds up, we expect there will be more droughts and more floods. Can we develop options to protect human life in low-lying areas? Is continued development of the coastline in fact tenable? Figure 4 is a picture that recently appeared in the journal Nature and it poignantly depicts how extreme events—in this case, drought—can cause human pain and misery.

Changes in frequency and intensity of forest fires are also of concern as climate changes. Figure 5 shows historic boreal forest fire activity and projections as CO_2 concentrations double. Catastrophic fires can release pulses of carbon into the atmosphere and the boreal forests hold a tremendous amount of carbon. In fact, during the climate negotiations, the Canadians had these model results and during their discussions with delegations inquired: "If the carbon we intended to store in forests gets released in fires, can we not be held responsible for those tons because it is an act of God?"

Figures 4 & 5

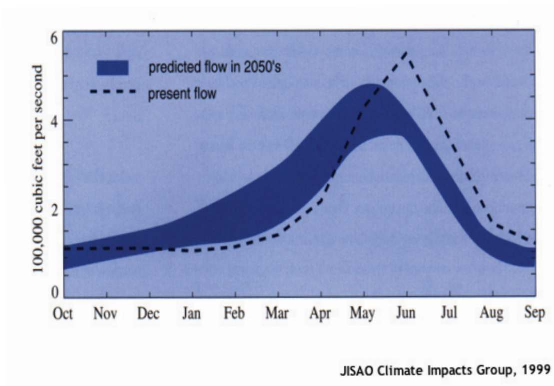


So whether we are talking about floods or droughts or forest fires, it is clear that we do not handle extreme events very well or optimally now. Learning how to do it better will be important security for the climate-changed world of tomorrow.

My fourth candidate topic, "Adaptive capacity and management options," is an area that has been very little researched. We know there is some warming in the pipeline, and while mitigation and slowing emissions remains very important, we are also going to have to cope with some level of climate change. I think we need to conduct many more "what if" experiments such as is depicted by this figure based on the Pacific Northwest region of the U.S. national assessment.

In Figure 6, the dotted upper line shows the current peak flow of water, which is in June; the blue band projects future water flow, peaking several weeks earlier. We brought together city planners, the hydroelectric plant operators, and the salmon managers, and they said: "If this is the water flow of the future, we are on a real collision course given projected population growth, electric generation needs, and in-stream salmon water requirements." Now that the problem has been identified, stakeholders can work together to identify ways to cope with this increasingly uncertain future. The Northeast regional assessment highlighted that, for Manhattan, the expected 20-inch rise in sea level poses potential flooding problems for subways, airports, and Long Island. Teams of stakeholders are now working to identify possible strategies to deal with these concerns.

Figure 6



The next graphic shows the erosion reference feature (ERF) for Galveston, Texas —mapping only expected erosion without adding rising sea level over the coming decades.

Figure 7

Galveston will be moving inland some 500 feet as shown by the red line. Sea-level rise and increased storm surges as climate changes would move this area of loss further inland and many more millions of dollars of real estate will be affected. I submit that it is time to begin analyzing how erosion, sea level rise, storm surges, and human desire to live on the coast, can best be accommodated. Participatory preparation for change—so we understand and develop appropriate adaptation options—is vastly preferable to reacting after the fact.

My last area is "Iterative assessment and synthesis." During 22 years in government, I only had two bosses, both of whom are in the audience today—Jack Gibbons and Neal Lane. Jack taught me that assessment is not a hobby. What is iterative assessment and synthesis? There are probably as many definitions of assessment in the audience as there are people, but to me it means stopping at a particular point in time, taking stock of what is known, what is not known, what is most important to know, what is knowable in what time frame, and helping to identify management options that make sense today, even as you are trying to resolve the remaining scientific, technological, and socio-economic uncertainties of tomorrow. Assessments must involve stakeholders and they must be iterative. One important product of an assessment is both in near-term and long-term research strategy. Scientists are loath to set priorities even within their own disciplines, let alone across disciplines; but as Neal Lane taught us, we must be "civic scientists." That means we, as the science community, must interact with the policy community or else research priorities will be set without our input and left to the interest of Congress and the administration.

In conclusion, I think the impacts of climate change will be manifested in three ways: in terms of degrees of temperature, in terms of the degree or summation of environmental insult, and in terms of latitude and longitude, given the vulnerability and adaptive capacity of the different regions of the world. I think we best get on with understanding all of these in a more concerted way.

ENERGY AND THE ENVIRONMENT: SCIENCE PANEL

Climate Science, Technology, and Politics: A Tangled Web

Robert White

You have heard our speakers innumerate many of the threats. I thought I would do something different. I will talk in general terms about climate science, technology, and importantly, the politics involved. It is a tangled web. If we go back nearly fifty years to 1957, it was the time of the International Geophysical Year. Roger Revell and Hans Suess first suggested that humanity was carrying out an important geophysical experiment by the release of CO_2. You have heard about the science results from Warren Washington and others.

Carbon dioxide has increased about 40 percent in the 20th century. Surface temperature has increased by 0.6°C. Sea level has risen about 10 to 20 cm. The midpoint of model temperature calculations is about 3°C, although it varies. In 2001, the IPCC estimated 1.4 to 5.8°C, with a projected sea-level increase of about 20 cm.

It took thirty years of international conferences of one kind or another to bring us to this point. In 1972, there was the first United Nations conference on environment held in Stockholm, Sweden. I was a delegate to that conference. In 1979, the World Meteorological Organization (WMO) organized the First World Climate Conference in Geneva. Thirteen years later, in 1992, the UN Conference on Environment and Development gave rise to the Framework Convention on Climate Change (FCCC). Then in 1997, there was the Kyoto protocol. We have heard much about energy issues, and climate change has emerged as an energy issue. The need for efficiency in decarbonizing our fossil fuels is now urgent, as is moving to non-carbon sources like wind, nuclear, solar, biomass, and hydrogen.

In 1990, the Congress legislated a national assessment. We just heard about the national assessment. The 2000 report included stakeholders and scientists and about 16 regions and sectors. You have heard about many of the impacts—permafrost in the Arctic regions, weather hazards, island inundation, coral reef bleaching, and many others. It was an excellent report, but it has not had a great impact, unfortunately. I think one of the reasons is that the two models that were used gave quite different results. While it has had little impact, it has been a treasure house of climate information. It is a remarkable assembly of information about climate.

We have heard some of the uncertain factors about the future. They deal with economic, technological, and population conditions. For example, who in this audience can predict what the political situation is going to be in the year 2100, even in the year 2050? What kind of wars will we be going through between now and 2100? What kind of political feuds will we have? And what about technology? Think back about fifty years. We had jet aircraft, but there was no jet air travel. Space technology was just in its infancy. Communication has undergone a complete revolution in the past fifty years. In biotechnology, I think revolution is just too mild a word; I do not know what to call it. Project yourself now fifty years into the future. Are you going to be able to predict what technology is going to be available to us? And finally, there is population. We have heard some of the estimates ranging from about 9 billion to about 14 billion, but these are uncertain. They are fundamental to our projecting the future of climate. One of the reasons why the IPCC projections from 1.4 to 5.8°C is so broad is because of the economic, population, and technological scenarios that were assumed.

Now we come to the political situation. First of all, there is the withdrawal from Kyoto. Vice President Gore, in a last-minute journey to Kyoto, got an agreement, because the conference was about to fail, that the United States would agree to emission reductions seven percent below the 1990 level by the year 2012. Of course the Senate opposed the commitment and voted 95 to nothing against the Kyoto Protocol. The basic reason was because it was not universal and it exempted countries like China and India. Then President Bush withdrew from Kyoto. Among the reasons for his withdrawal was that the science was very uncertain. There was also the economic impact of emission controls. He proposed a new climate effort that would involve the reduction of carbon intensity.

Now we go to the Congress. I quote from a speech to the Senate made by Senator James Inhofe (R-OK), who chairs the Committee on Environment and Public Works: “Scientists vigorously disagree over whether human activities are responsible for global warming, or whether those activities will precipitate natural disasters.” In turning down the bill last October (2003), he made similar statements. Senators John McCain (R-AZ) and Joe Lieberman (D-CT), on the other hand, have proposed a cap-and-trade process that mandates controls on CO_2 emissions. There you have both sides. Actually the vote was sort of favorable to the environmental side; they got more votes than they had anticipated, and the vote was about 56 to 43. And then there are other political actions on both sides. California, nine other states, and a variety of environmental organizations are in the process of suing the Environmental Protection Agency (EPA), because the EPA does not include controls on CO_2. At the World Climate Conference in Moscow in October 2003, President Vladimir Putin delayed his decision on ratifying Kyoto. The reason that is so important is that, unless Russia signs up, we cannot get the 55 percent of emitters to get the agreement ratified. As indicated previously by speakers, the Bush administration has instituted a new climate change science program. Fifteen hundred people came to a session in Washington to debate the issue of climate change science. Individual states are now moving ahead on their own. Maine has actually set goals and timelines for CO_2 emissions. Abroad, the prime minister of the United Kingdom, Tony Blair, has announced a 60 percent reduction in greenhouse gases by 2050. And finally, after the European heat wave this past summer, which was very intense, Rajendra Pachauri, who was the chairman of the IPCC, warned of global warming.

The Bush administration has established a cabinet committee on climate change. They want a new strategic plan for the U.S. climate change science program. Another item: industry, which up until recently has been very reluctant to support technological developments related directly to climate, has just contributed $200 million to Stanford University for research on energy issues related to climate. Last week, a new report by the Energy Futures Coalition was issued, which charts a new energy future—a very interesting document.

That, ladies and gentlemen, summarizes both sides of this climate dilemma that we are in. We have a variety of views on the climate and where it is going. The only thing we have is agreement on what has happened during the 20th century. How it will come out, I do not know. We shall see.

ENERGY AND THE ENVIRONMENT: SCIENCE PANEL

Equity, International Dimensions, and the Role of International Science

Richard Anthes

I am going to depart a bit from what you have heard so far this morning. I will probably end up arguing that climate change is one of the least of our worries, just to be a little provocative. Part of this presentation is from a talk I gave at the American Meteorological Society (AMS) annual meeting in 2002. The AMS asked "how should we change?" This presentation is an updated version of that one. Our community, the AMS and the University Corporation for Atmospheric Research (UCAR), wrote a short document about some of the ways that atmospheric sciences could help with the challenges since the 9/11 tragedy. Our response included some of the things you might expect, like weather support of our military and citizens in dealing with release of extremely toxic hazards, either gases or other materials, tracking these materials through impossibly complex street canyons, and that sort of thing. Atmospheric sciences can also play a significant role in mitigating other environmental threats and stresses, ranging from very short time scales of hurricanes, storm surges, wild fires, and so on, to longer time scales that include the economy, health, agriculture, and industry. On the short time scales, we can make ourselves more resilient to forest fires, pollution events, severe weather, hurricanes, etc. But then we also have to consider the longer time scales, including climate change, which you have been hearing about this morning. And the questions associated with the different time scales are related. Are hurricanes going to get worse? Are forest fires going to become more or less frequent? How can atmospheric sciences contribute to our economy, health, agriculture, industry, and so on?

I am not going to talk anymore about atmospheric sciences and the importance of climate, not because I disagree with anything that has been said so far, but because there are other issues that I think are even more important to humanity and to the United States than climate and severe weather. Even if climate stayed exactly the same as it is right now (which is almost impossible to believe because it has never been constant; even before humans were around, the climate was changing), society has many other important issues to worry about that policy makers have to address. The key drivers are population growth and the increase in per-capita consumption of resources by the increasing population. You might argue that the population will level off smoothly and gradually at

9 or 11 billion; but there is also at least a chance of a draconian scenario—that the exponential growth will just collapse, for reasons we cannot predict, in a very non-gradual way from one or a variety of social and environmental problems. The long-term issues of growing population and related problems form a much greater security threat to our nation and world than that of climate change or sporadic episodes of terrorism like 9/11.

What are the broad security issues? Security is one of our top national priorities right now, right up there with economy. Security is often thought about in a very limited way: reaction or protection against terrorists or military threats. But we have much broader security issues involving overpopulation, the crowding and associated competition for resources, poverty, disease, aggression, hatred, religious extremism, intolerance, and so forth. These are all mixed up and connected. They are likely to be exacerbated by climate change, but even without climate change, these factors are still going on. To people who say, "Well there are plenty of resources, plenty of water and energy to take care of a 12-billion-population world," I ask them if they are satisfied with the state of the present world at 6 billion, where 25 percent of the 6 billion people make less than a dollar a day. Are you satisfied with that? Maybe we could sustain 12 billion. Maybe we could sustain 50 billion. But do we want half or more of those people making a dollar a day and dying at the age of 20? I do not think so. Involved in all of this are the huge inequities that we have already seen this morning associated with the richest countries spending most of the resources, leading to huge inequities in the standard of living, health care, etc.

So even if we solved the weather prediction and climate science challenges, and we could get all these wonderful satellites in place and could make perfect predictions and perfect climate projections—we make Warren's models perfect instead of just very good—it is not going to make much of a difference if these other social factors are not solved.

So what should we do? Let us go back and look at one example from history—the fall of ancient Athens. If we think that the United States is going to go on forever, no matter what the rest of the world does and no matter what our internal attitudes are, consider the fall of Athens. There were major earthquakes in 464 B.C. and 426 B.C., and there was a plague in 430 B.C.—all in less than a hundred years. The plague killed one third to two thirds of the population, and it returned three times. The combination of the plague and the earthquakes helped lead to Athens' defeat in 404 B.C. by Sparta. The Athenians could not cope with natural disasters. But there was more to the demise of Athens than these disasters. Here is another point of view from Edith Hamilton, author of *The Ever-*

Present Past (1964).

> In the end, more than they wanted freedom, they wanted security. They wanted a comfortable life and they lost it all—security, comfort, and freedom. When the Athenians finally wanted not to give to society, but for society to give to them, when the freedom they wished most was freedom from responsibility, then Athens ceased to be free.

So, what should we, the world, do? I strongly believe in investing broadly in science and education. Especially, even though I am a natural scientist, we should invest in the social sciences—history, cultures, and languages. It is really shameful that most of the people in our country only speak one language and many people experience and appreciate only one culture. We think that our particular culture is a God-given constant; it is our God-given right that we maintain our culture. Many in our country believe that other cultures are less important or are inferior. So we must spend a greater effort educating people in science and in the humanities.

Let us consider one example of the difficulties we scientists are facing in educating the public. In trying to convince people that global warming is a reality, we try to explain to them radiative trapping of heat. But according to the latest National Science Board's *Science and Engineering Indicators 2002*, less than half of the people in the United States know that the Earth goes around the sun once a year. How are you going to explain radiative trapping of heat to these people? Fewer than half, in an essay question, can answer correctly why winter is colder than summer in the United States. Most say that the Earth is closer to the sun in summer. This widespread scientific ignorance of the basics that determine our climate and other aspects of our home planet is an endemic problem in our culture.

So what should the United States do? What about us? We should better understand our role in the new world and the complementary roles of others who think differently from us. We should become less arrogant, better citizens of the world. We must not always put the U.S. economy and our consumerism as our highest priority. We should work more cooperatively with other nations on issues such as global air and water pollution and climate change. I do not think we can remain isolated and indifferent to the needs and wants of others for much longer. In summary, it is impossible to imagine a healthy United States in an unhealthy world.

So addressing these global issues requires wise and thoughtful leadership in the United States. It requires something that is badly needed and that I have not seen much of in quite a few years: bipartisan leadership, similar to the brief effort following 9/11 but one that lasts indefinitely. We need leadership that quits pointing the finger at other nations or at other parties and realizes that we are all in this soup together. We are not going to solve this, one party, one administration at a time. And I would like to see our leaders and the public take a longer view. We have heard long views this morning from every speaker. But anything you read in the newspapers and the magazines are about very short-term views. Sure, we can probably muddle along for another year or two or three, but we cannot muddle along forever.

I will close with a quote by Tony Blair just after September 11, 2001.

> We could defeat climate change if we chose to…. But it's only a start. With imagination, we could use or find the technologies that create energy without destroying the planet; we could provide work and trade without deforestation. If humankind was able to finally make industrial progress without the factory conditions of the 19th century, surely we have the wit and will to develop economically without despoiling the very environment we depend on.

ENERGY AND THE ENVIRONMENT: SCIENCE PANEL

Discussion

Question: I would like to ask a question of Warren Washington about priorities on climate change. It would seem like a priority that climate change should be the role of carbon accumulation and gas hydrates. The question is: Should gas hydrates be a priority in climate change?

Washington: As you know, the climate change science program has just started in these last few months. It is trying to address many aspects of climate change. But one of the highest priorities is to establish the carbon cycle and to understand such things as the carbon trapped in the bottom of the ocean, such as the gas hydrates. I think that there are many serious scientific questions that we do not understand fully, such as the gas hydrates and its possible role in future climate change.

Question: You summarized the agreement between observations and theory on a global basis. Could you say a little bit about the correlation? Is there confirmation of predicted regional effects as well?

Washington: I did not have time to show extensive amounts of regional information, but basically what the models show is that in the higher latitudes, especially in the northern hemisphere, we see the largest temperatures changes mostly in winter. The observed temperature increases are consistent with the model predictions. Also, we know the water vapor feedback and the ice-albedo change are the leading causes for the amplification in those regions.

Question: I would like to ask Dr. Bierbaum if she could give us a little feel for the impact of climate change on the developing countries, because we seem to consider things from our own position here.

Bierbaum: One of the comments that came out of the new IPCC report is that the areas with the least resources are likely the most vulnerable—i.e., the developing countries. The reasoning behind this is developing countries in general tend to be more dependent on natural resources for their economy and have less economic and technological capability to address adaptation and coping. If we talk about sea-level rise in the United States over the next century—we are expecting something like 7,000 square miles of inundated wetlands and dry lands —I would argue that we would probably be able to figure out a way to cope with this, even in the Southeast and Galveston, regions most heavily affected. But if you think about the low-lying states like Bangladesh, a sea level rise of one meter would take out 13 percent of the land area and some 18 million people, creating environmental refugees of historic proportions. Similarly, the low-island states face inundation. In terms of agriculture, the best estimates of global agricultural productivity increases suggest that the United States and Canada might increase their productivity on the order of somewhere between 10 and 40 percent, but again, it is the poorest regions of the world—Africa and South America—that stand to lose productivity on the order of 30 to 60 percent. So even though there may be a warmer, wetter, greener world that has enough food for the population of the future, the distributional aspects appear to be heavily weighted against the developing countries.

Question: I have a question for John Holdren. The essence of this meeting is to explore this interface between science technology and policy. So my question is: How do we move ahead in the political front? What thoughts do you have about how we as a community really begin to assist the enactment of the kinds of changes that have to be made?

Holdren: That is a huge question. There are some fairly trite answers, but I think there is some wisdom in the trite answers. One of them is that more people from the scientific and technological community have to become involved one way or another in the policy process. That may be the process of educating their own policy makers, their own representatives in Congress. It may be spending time in the relevant agencies in Washington. It may be educating their neighbors. But I have a proposition that suggests that everybody in science and technology —recognizing the social impacts of everything we do and recognizing that we cannot predict all the adverse consequences of some of the things we do—tie 10 percent of our time to the political process. That we try to see that the insights of science and technology are put to the best use in our society and that the worst uses are avoided. If people took that sense of social responsibility as a 10 percent effort seriously, I think we would considerably improve the prospects for making progress.

Question: Many of us in this room would like to see aggressive actions taken to affect the kinds of changes Holdren described in terms of the energy system and in avoiding these major consequences of change. On the other hand, Holdren made a pretty convincing case that, frankly, we are not going to get there. Bierbaum and MacCracken both touched on the idea of adaptation, not necessarily in place of, but perhaps parallel to, mitigation. Can you comment on where you consider the level of thought on adaptation, research, and on, perhaps, measures? Just as we need early moving measures on avoidance of carbon emissions? The time scales are comparable. What should we be doing in terms of really moving actions in adaptation?

MacCracken: The fundamental purpose of the U.S. National Assessment was to get at this issue of "So what?" Given that we have some understanding of the science, "Is there something we can do to prepare?" If you look at the climate results, it is very clear. The climate change is going to continue even if we went to zero emissions, and that is not going to happen soon. Our sense was that you cannot mandate adaptation from the top. What you really have to do is go out into the country, into regions, into various sectors, and discuss with people what the science is and let them figure out what the best thing to do is. Dr. White commented that one of the problems with the assessment was that its climate model scenarios differed. I do not know of any scenario analysis where you would want to have scenarios exactly the same. The whole idea is to have them differ to understand what different conditions can be. Indeed, that the scenarios differ is a criticism that is sometimes made, but I think it is completely the wrong one. There is a lot you can learn by going out and looking at what happened in the assessment process. If you look in California, for example, even though we do not have details of what exactly is going to happen with snow cover and rainfall, it is very clear that warming is going to cause the snow line to go up. This is going to cause tremendous problems with respect to water resources. We also know the increase in CO_2 helps the chaparral grow better. A little bit better rains make it grow better. Improved CO_2 improves the water use efficiency of chaparral. Instead of chaparral growing up and accumulating a fuel load of 25 years and then burning, the burning is going to happen in 15 years. If we have any common sense, what we will do is build houses that are not susceptible to fire. There is a lot more we can do right now to take the knowledge we have and figure out how to adapt, but I think the only process that is going to work is one that gets people talking about projected climate change and lets them discover what those changes are.

Comment: I want to comment on Moniz's question on adaptation. There are two kinds of adaptation. One is what I would call "realistic immediate adaptation." We have a flood, we have a frequent flood, we do something about the flood plain, and we build barriers against coastal inundations. We have the other kind of adaptation, which is an "anticipatory adaptation." That is, you anticipate that you are going to have to adapt. My view is that we have such a growing arsenal of technological capabilities that, with the proper political and financial will, we can adapt in an anticipatory way. So I think we have to make sure that we understand what kind of adaptation we are talking about.

Bierbaum: Just to build on what the others have said: At the moment it is sort of nobody's job to think about adaptation. The new federal 10-year research plan is rather light on moving in that direction. As MacCracken said, the assessment showed us that if you sit down and think about the intersection of fish, hydro, and city growth, you could begin to understand potential problems and move towards the anticipatory adaptation and identify missing research needs. To the extent that adaptation research is being done, I would say it is being done more on a sector-by-sector basis. And yet, of course, climate change will have impacts on all sectors simultaneously. Jack Gibbons and I did a study at the Office of Technology Assessment (OTA) on adaptation about a decade ago called "Preparing for an Uncertain Climate," and basically we concluded that adaptation measures should seek to increase our resiliency and flexibility to change because in fact, for the foreseeable future, especially on a decadal time frame, you may need to be able to adapt to increasing uncertainty. For example, U.S. water models are built on the assumption that the last hundred years are a good surrogate for the future. We know that is wrong. If you think about protecting wetlands, we should maybe be putting an additional metric in there about whether coastal wetlands that we are trying to preserve can in fact persist as sea level rises. Or think about the $8 billion ongoing replumbing effort in the Everglades, a third of which may be underwater because of sea level rise over the next century. I think a very simple "what if" analysis can lead to adaptation options, but I think the problem right now is that it is no one's job to do it.

Question: As a concerned citizen, I would like to ask the whole panel how the average citizen can deal with what seems to be a deliberate campaign of misinformation from the current administration and a spinning of scientific facts that is not based on ignorance, inadequate science, but rather a deliberate spinning of scientific facts. And for the average citizen, it is an increasingly complex issue not only because the facts are complex but also because the spinning is more deliberate. Can anyone answer my question?

Panelist: I am not sure how to answer the question. Individuals have ideas that are based upon data, things they read, and they come to conclusions and views. They have every right to and ought to advance those views in whatever form they can, until they can convince the political entities—whether they exist at the local, regional, state, or federal level—to take action. It seems to me that that is the way in which individuals who feel very strongly about protecting the environment have to achieve their goals. We do have many groups, environmental advocacy groups, operating at these various levels that are having an enormous impact on these things. So I think that that is the way to do it—operate at the political level, whether it is in your locality, your state, or federal, to get them to change their minds. This kind of public communication is so important. Do not forget what people said. We have a very short memory, so keep a record of what was said two years, five years, six years ago, and expose these things to the light of day. I suspect there is probably a third of the people in the country that have their minds completely made up on either side of any issue, and there is maybe a third, if we are lucky, in the middle that may be convinced. But it is partly a huge public education effort that I referred to. It is constant, you cannot say it once, you have to say it a hundred times. Tell them the Earth goes around the sun.

Question: The topic of this few days is bridging gaps among academia, policy makers, and industry. This panel is on energy and environment. There seems to be a gap between policymaking—i.e. the public—and industry on environmental issues related to energy. It seems that no matter what industry tries to do and to explain, still we do not get a public opinion. The question is: What can we do more effectively in order to bridge the gap of perception of the world of the energy industry in environmental safety? Right now we seem to be in agreement.

MacCracken: I think, on the issue of climate change and adaptation, we tried during the U.S. National Assessment effort to involve industry. One of the things that was done was to not carry out the Assessment as a series of reports out of Washington mainly, but to do it in various regions, to base those studies in universities and have the universities invite scientists and environmental groups and industry groups to come. Many people came to the workshops, but industry tended to be reluctant because it was during the time when they were fearful that if they came and agreed, the Kyoto Protocol might be approved in some sense. But a lot of them came, and we had some very interesting interactions with them. I guess generally I am positive about getting industry involved. Let me just say, however, that there is right now a particular industry not far from here supporting groups that have filed lawsuits to try to suppress scientific information and withdraw reports. There was a very interesting lawsuit that was filed in October of 2000—it was against William Jefferson Clinton, a citizen of New York residing in Washington, D.C., and Neal

Lane, director of OSTP, who spent a lot of effort standing up to a lot of comments that were coming from Congress to try to help to explain these issues over time. We really do need to get industry involved. IPCC is working hard to do that. The review comments we have gotten from industry in that process have been very helpful. But they have to come to the table and discuss the issues.

ENERGY AND THE ENVIRONMENT: TECHNOLOGY PANEL

Energy Efficiency

Henry Kelly

Let me start off by being clear that when I use the term “efficiency,” I am really talking about productivity. What this means is how much you get out of what you invest. You can increase output by simply working harder—putting in more hours, investing more capital, using more energy, or buying more services. But you can also increase output through new technology that produces more output from the same set of inputs

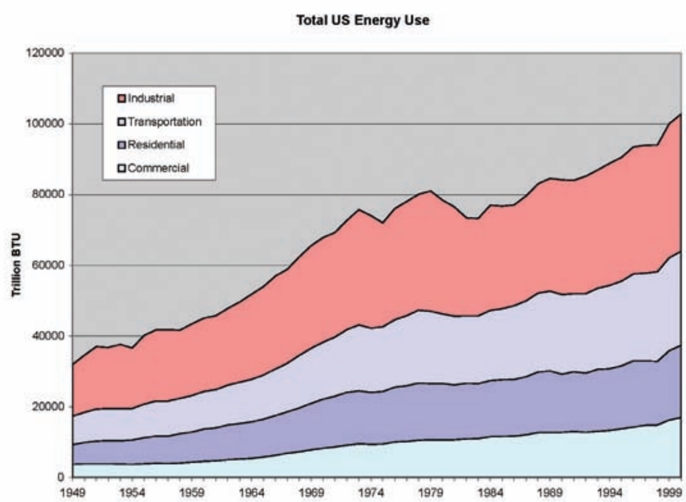
John Holdren eloquently pointed out that strategies for reducing energy use are central to solving environmental problems. Techniques for using energy more productively—using new technology to get more out of the energy that we are investing in—are, in turn, central to cutting energy use without sacrificing amenities or opportunities for economic growth.

We have, of course, been working to improve energy efficiency for some time. You might expect that we have picked all the low-hanging fruit, and there is not a lot of room left for improvement. But in fact, if you compare the theoretical minimum amount of energy you need to accomplish most of the things we do—such as cooling beer in your refrigerator—the actual amount of energy we use is often many times hither. We are not anywhere close to an optimum in most areas. We can, and must, achieve enormous improvement in energy productivity across a broad spectrum of economic activities.

In this talk, I will review very briefly where we can look to find the technical improvements needed to achieve these productivity gains. The burden of my argument is going to be that the investments we need to make, to achieve these very large changes in the links between energy and output, are precisely those that will increase the productivity of the economy as a whole, investments in biotechnology, information technology, and nanotechnology. Those lie at the core of not just trivial changes between the relationship of labor capital, energy, and output but offer the opportunity for an order of magnitude change.

We have a lot of work to do. If you look at just energy use in the United States (Figure 1), you see a continuous increase in the demand for energy during the last ten years. Our energy productivity is going up, but our demand is going up faster. There was a brief period in our history, after the energy crisis, where U.S. energy use was roughly constant. But today, no matter how we spin this, the demand is going up. If you look at Figure 1, a good chunk of this growth is in industry (shown at the top), the middle bar is transportation, which has been growing faster than any of the others, and the bottom is commercial and residential buildings.

Figure 1



The challenge talking about energy technology is that while general principles apply, the different strategies apply to each sector. You have to deal with each, so I am going to try to do that for you.

The first thing you should recognize is that even though our energy is going for very exotic things, in fact, most of our energy goes to do very familiar things. Consider residential buildings (Figure 2a). Enormous amounts of energy are used to heat houses and hot water. You can always tell that your state of knowledge is in trouble, however, when the largest category in the chart is in the category "other." In Figure 2a, you see that "other" electric uses are starting to run away with the show. Nonetheless, if you look at residential and commercial energy use (Figure 2b), a large fraction of the energy is still going to heating, lighting, and heating water. What can we do about this?

Figure 2a

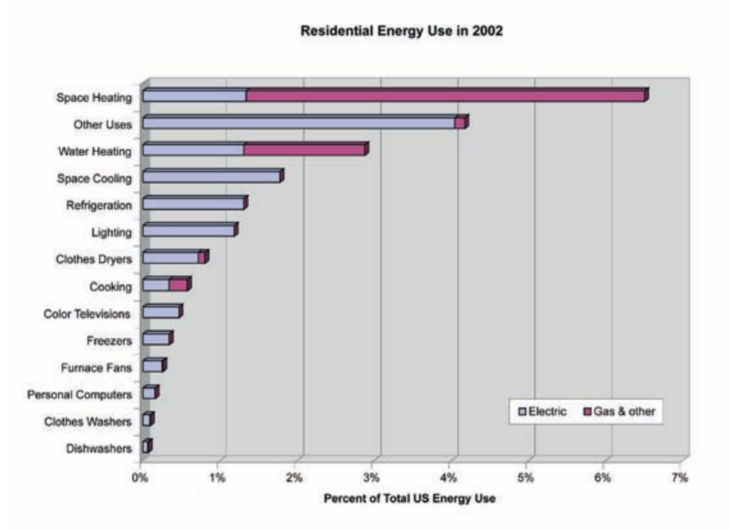
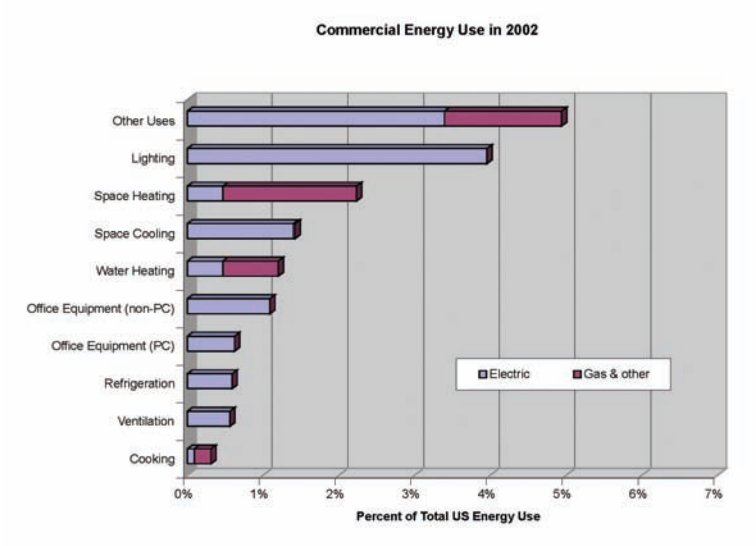
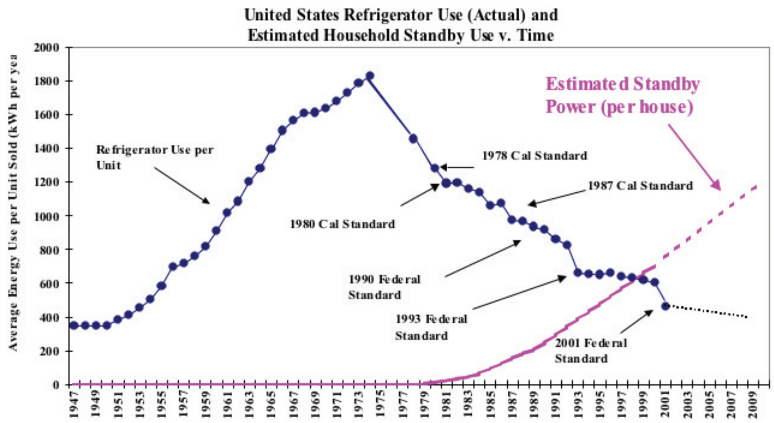


Figure 2b



One major success story is in refrigeration (Figure 3). The energy used by a typical refrigerator increased steadily until an energy policy statement was made in the form of a regulation passed in the mid-1970s, after which you see an enormous decline in electricity use in refrigerators. This happened when the average volume of refrigerators doubled. This is quite a spectacular achievement. How on Earth did that happen? When you looked at how the old refrigerators were designed, it would not be hard to figure out how they managed to use so much energy.

Figure 3



The opportunity is there if you have intelligent focus on it. But what can we do with the mysterious "other" category? A major part of the problem turns out to lie in the little black boxes that are all over your house. You probably own dozens of these things to convert 110-volt electricity from your outlet into the voltage you need for your computers, your modems, and your garage door openers. The average use of each converter is 15 watts. You can see from Figure 3 (where they are called "standby power") that they are growing rapidly.

I do not have the time to go through the analysis in detail, but a good fraction of the electric demand growth in the United States over the next ten years could be met simply by having everybody shift to energy-efficient appliances already on the market.

Let me turn briefly to another unromantic problem and ask the question: "How do we get the smart guys in this room focused on the kinds of technical problems that are critical for cutting energy use and improving the environment?" It turns out that one of the core technical challenges is the seemingly unromantic field of window technology. There seems to be nothing more boring than windows, but the amount of energy associated with windows is roughly the output of the entire nuclear industry. So on some level, you say window technology ought to be equivalent to the nuclear engineering department, but it is not. To stir the grey matter up a bit, let me give you Kelly's definition of the ideal window:

- Controllable emissivity
- Controllable transmissivity (visible, IR)
- Convert non-transmitted energy to electricity
- Control air transport/ventilation

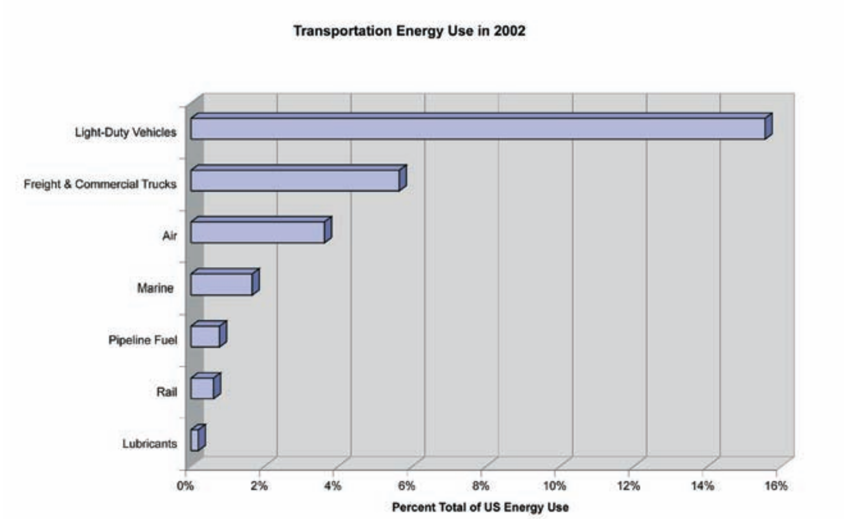
- Resist penetration during strong winds
- Light producers as needed
- Patterns/images?

This is a semi-impossible set of goals, but they are not unachievable. Notice first that these goals focus on many dimensions of utility—not just energy.

What about the building shell itself? It is another unromantic technology. Huge amounts of energy are going to just heat buildings. The technology of the toaster ovens has probably received more R&D than building shells have in the entire ten thousand years of human habitation. Let us focus a moment on what an ideal building shell would accomplish. It would be inexpensive to build and maintain, stand up to hurricanes and earthquakes, reduce mold and termites, and have excellent thermal properties. Can we do that? If you were going to start from scratch, would you start with 2x4s and gypsum or would you start with something else? There is a whole series of really interesting composites that you could talk about in this field.

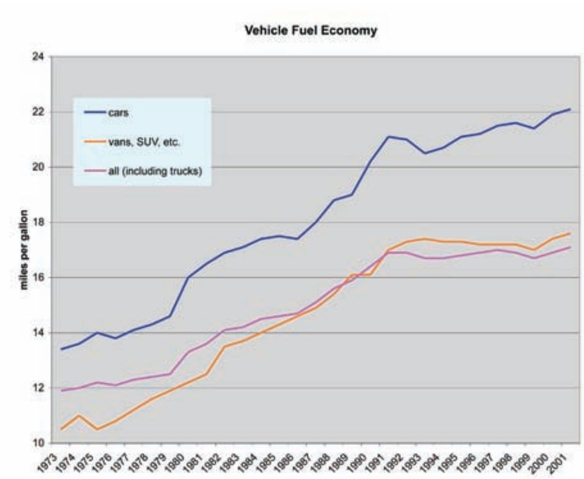
I will now turn briefly to transportation. Transportation energy use in the United States is dominated by light duty vehicles (Figure 4).

Figure 4



Light duty vehicles are the official term that combines cars and everything else we claim are cars even if they look like military vehicles. If you look at the fuel economy of these vehicles in the United States (Figure 5), you can see the average efficiency of cars on the road keeps drifting up.

Figure 5



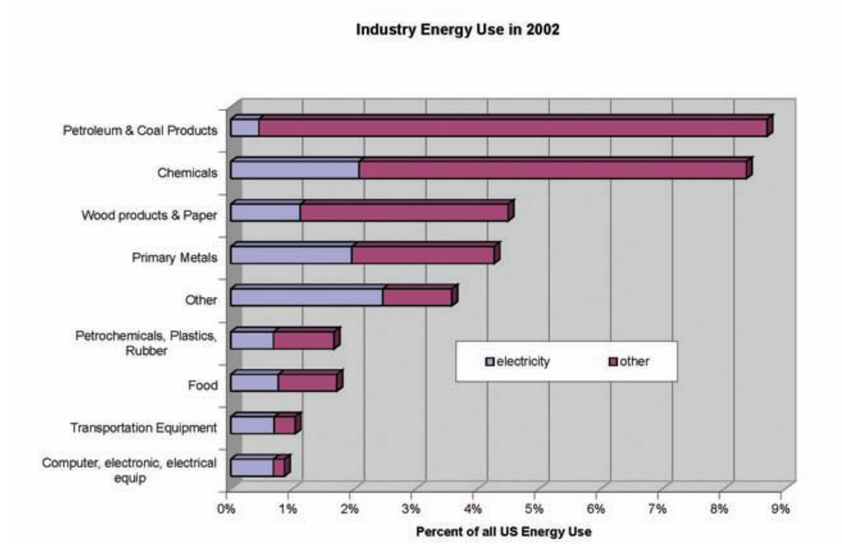
This is because we are still benefiting from the fuel economy standards passed in the early 1970s. But the fuel economy requirements have not changed since the 1980s. Since many SUVs, vans, and trucks are being driven like cars, the average miles per gallon of vehicles on the road has not changed for over a decade. This has been a complete disaster because the per-capita miles traveled keep going up, about three percent a year. The other worrisome thing is that, as incomes rise in China and other places in the world, one of the first things they want to spend their money on is a modern car or SUV making this not just a domestic but also an international problem.

The good news is that large factors of improvement are achievable through a combination of more sophisticated fuels and engines and drive trains. There are two key things to worry about. One is trying to figure a way to store energy on board that is safe, easily convertible to power, and that conforms to the volume constraints of the vehicle. The second is short-term energy management. If you want to run a hybrid, you need a system that temporarily stores the energy captured when the car is stopped and get it back to the wheels quickly and efficiently when you restart the car.

I will give you two existence proofs to demonstrate that we are a long way from perfection in both categories. First, we know that biological systems are able to store large amounts of energy safely. A few dog biscuits can power a dog for a considerable time—and they are safe to store and biodegradable! For transient energy storage, all commercial hybrid vehicles use electric batteries. This requires many conversions. The energy starts as kinetic energy as the car is in motion. This is converted to electrical energy when the car brakes and then is converted to chemical energy in the battery. Then you have to reverse all this to get energy back to the wheels. If you can get 30 to 40 percent back out, you are lucky. But compare this to a natural system for doing the same thing. A kangaroo hopping forward is able to store energy in tendons that act like springs. They get something like 60 percent back out. A good spring can get at least 90 percent back out. It should certainly be possible to start approaching this in the design of hybrids.

Now, I will turn briefly to industrial energy use (Figure 6). One of the interesting things is that the biggest industrial energy consumer is the energy sector itself—particularly petroleum industries. Energy used to produce energy. A big chunk of industrial energy is the roughly four quads of fuel that we use to make asphalt, a large amount of which is used for roads. The top bar and a good fraction of the glass and metals are essentially part of our transportation system. One of the biggest technical challenges in meeting industrial energy demand more efficiently lies in efficient design and production methods. Ideally we would want on-demand production of lots of complicated things, using very inexpensive, widely available materials. And you would like everything to be recyclable.

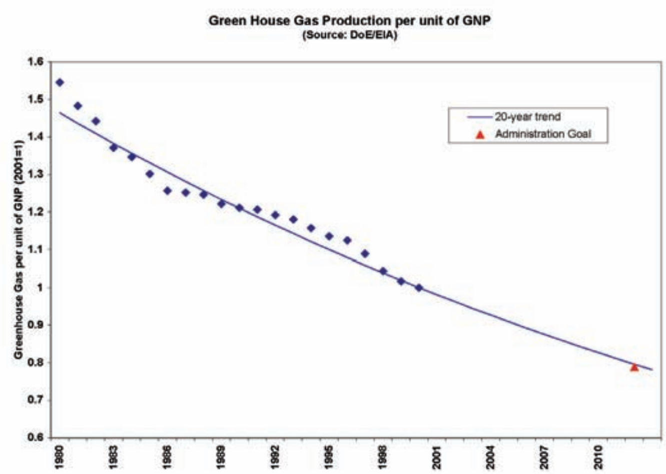
Figure 6



We see the glimmer of this in the potential of things like nanotubes and buckyballs. The primary material is carbon, and you would like to be able to have it so it is recyclable. Once again, we can look to biological systems to see what may be ultimately possible. Living cells have codes for hundreds of thousands of different chemicals they can make on demand. They can make materials of all sorts—bone, hair, webs, mother of pearl—and assemble them into complex and wonderful things. This surely sets the challenge for what can be achieved with sophisticated manufacturing processes.

John Holdren challenged us to ask: Are we are holding ourselves to ambitious and practical objectives? The Bush administration has set the incredibly bold goal of keeping ourselves on a 20-year trend line (Figure 7).

Figure 7



This is not going to be enough. This is not to say that maintaining this trend line is easy; there has been a lot of hard work done over the previous 20 years to keep this trend going. But this is plainly not a goal that is going to get us the environmental benefits we are looking for. It falls woefully short of the technical promise of the systems that we are talking about.

It is painful to set our goals so low since it is abundantly clear that we can achieve enormous improvement in energy productivity through disruptive technologies we can already envision, and since those are also the technologies we need to ensure U.S. competitiveness, and to provide a better life for ourselves and for people worldwide. The technical problems are hard but we know what to do.

The political problem is that we are locked in this ridiculous debate about Kyoto and failing to focus on the question of how we can actually accelerate the development and use of these technologies. How do we provide the incentives for people to focus on problems like windows? How do you get the technical capabilities that actually could lead to disruptive technologies that could make a huge difference for the environment? We must find a way to change the terms of the debate. The nucleus of that consensus can surely be found in agreement that we all want to promote technology that can lead to a sustainable, productive, and prosperous life. This is the core question that this conference should focus on.

ENERGY AND THE ENVIRONMENT: TECHNOLOGY PANEL

The Energy Supply-Side Challenge: Barriers to Innovation for Renewables, DG, and Base Load Technologies

Larry Papay

I presume that I am the "supply side guy" for this panel. In looking at the agenda, I guess I am the industry guy, too. I want to focus on the supply side, and I am going to look at it in a little different manner from what people have in the past, because I feel challenged to try to make my comments a little more productive.

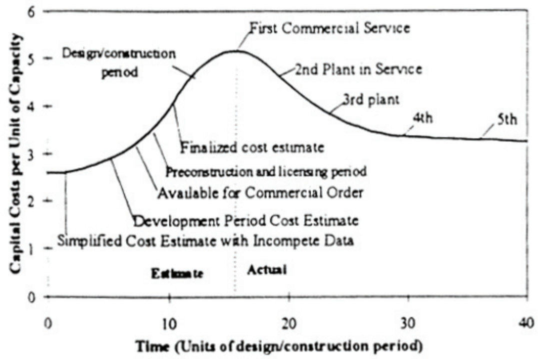
We are going to talk about it in terms of the laws of energy research and development (R&D). The first law is: "The further off the technology is in the future, the lower the estimated commercial cost of it." So anything that is 50 years out always looks like it is going to be more cost-competitive and lower-priced than anything that is here or in the immediate future. Unfortunately, it also looks more benign the further off it is in the future because the impacts of fully developing a technology, bringing it in, and deploying it in any large scale manner also has environmental assumptions associated with it. This is the second law of energy R&D: "The further off in the future the more benign the technology." The third law of energy R&D is quite simple: "If you do not know where you are going, you will not know when you get there." So you have to understand where you want to be at some point in the future. That becomes very important, as we will see.

In looking at the first law and the second law of energy R&D, there are two economic considerations on which we spent a good deal of time in PCAST 1997: the "mountain of death" and the "valley of death."

Consider the R&D process as John Holdren talked about it—R & triple D—not just research and development, but research, development, demonstration, and deployment. Since I represent the industry end of things, I am linked to the last two D's. How do you demonstrate and how do you deploy?

In one sense, the R&D part of it is easier, if the funding is there. You run into problems when you start to look at the early deployment of a technology, the so-called "mountain of death," (Figure 1a) because, as the first and second law of energy R&D state, you will find that there are incremental costs associated with the early deployment of the technology.

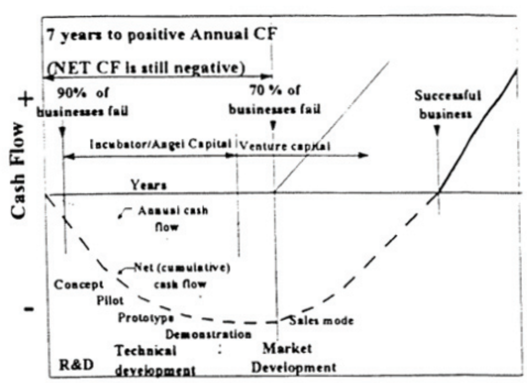
Figure 1a



That is a universal fact. There are costs associated with first-of-a-kind planning and engineering, and it is only after you get through that first-of-a-kind process that you begin to get the economies of scale and the economies of repetition coming in. Then you can drive down the cost. So the mountain of death is an important element in trying to bring a new technology to bear.

There is a companion issue, the so-called "valley of death" (Figure 1b). This is what drives individual companies in terms of when they reach financial break-even, and when they are able to make money. Do they have "patience money?" Do they have the time and the wherewithal to invest money, such that eventually they will have a successful business at some point in the future? It is an important issue when we talk about deployment.

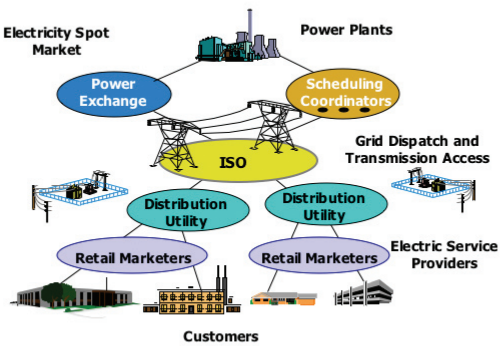
Figure 1b



Domestically, we have had an extremely difficult time, particularly in the last decade or so, because there has been so much cheap, natural gas available. It has made any technology, other than natural-gas-fired combined-cycle power plants, unattractive economically and, therefore, any new technology even more unattractive because of the cheap alternative being there.

This is my whole technology slide (Figure 2). I could show you pictures of nuclear plants, coal-fired plants, gas-fired plants, wind turbines, etc. Conceptually they are all included in this chart.

Figure 2



There is a tendency to pick out individual technologies, to say that "we should do A rather than B." My point is this: no one size fits all. We need all energy technologies. If you look at a given situation, you will find that given a grid or lack thereof and given a set of fuel characteristics—price and availability—there will be a certain technology or a suite of technologies that is more attractive for that given situation. For example, in trying to make photovoltaics cost-competitive against natural-gas-fired combined-cycle plants in the United States—where we have a very good grid system and we have had fairly cheap natural gas—we are handicapping the commercial introduction of the technology. That would be the wrong place to try to first commercialize photovoltaic power systems.

If one looks at Third World countries where there are little or no organized energy systems, which John Holdren talked about this morning, where the price of diesel is 70 cents, or $7, or $70, or more because of delivery costs, photovoltaics and other renewable technologies look a lot more attractive. You have to pick your spots to introduce various energy technologies as a function of the technology and what the fuel and the grid arrangements look like. All technologies have a best-fit scenario; they all have a place where they are competitive. And as we will see, there is a need for all of them.

One of the interesting things that we have found happening in the United States within the last 15 years or so, based on legislation dating to 1978, is that we have begun to transform the electric power industry in this country. We have introduced new players in the game; but in doing so, we have made it more difficult to be able to bring about changes in technology because short-term economic considerations, and not longer-term goods or services, are driving every decision. So the key considerations that we are confronted with today are numerous. First of all, we have the market drivers. Also, deregulation and disaggregation in the utility industry impact negatively some corporate economies of scale that used to be available. Complexities in the market place, changing energy prices, and things of that nature have also made it much more difficult to introduce new technologies. On the other hand, major consumers are now looking to manage their energy supplies differently. As Henry Kelley pointed out, that may be a good thing because that may be driven by other, better considerations.

Technological innovation tends to be incrementally driven, which makes it difficult in this particular environment. Break-out technologies are even more difficult to bring about. The consequences of this are that we need incentive mechanisms if we are going to introduce technologies on a domestic basis. We have done it in the past—we have used tax incentives and other mechanisms. Maybe renewable portfolio standards, things of that sort, may help out.

One of my premises today is that international opportunities are really where payoff can come about more easily, but we need cooperative mechanisms. How can we proceed? We have to look at the innovation process and look at how we can bring new technologies or incrementally improved technologies into the market place. And we need to look at the policies that are involved; and those needed for technological options for future demand; and to look at the forces shaping the future demand.

The critical point is the need for policies affecting large social issues, particularly in developing countries with urban and economic growth. As John Holdren mentioned, with global change and climate the leading issues, we need to consider once again the issue of internalizing externalities. It is increasingly important in today's society.

Also, we are moving towards a digital society, while the grid systems that are in place are analog systems. One cannot get the reliability and the quality out of an analog system that is needed if a society is becoming digital. This is true both for the developed and the developing worlds. So this is another driver that can help us, in terms of new technologies, as we move forward.

Let me focus on the question of urbanization in the less-developed world. There is a new National Academy report, titled *Cities Transformed*, which looks at what is happening in the world today and in the very near future (Figure 3).

Figure 3

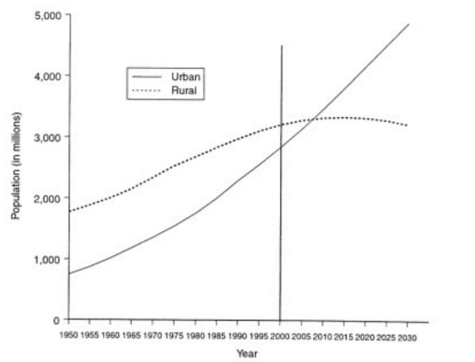


FIGURE 1-1 Estimated and projected urban and rural populations, world totals 1950–2030.
SOURCE: United Nations (2002a).

It does not go out to the year 2100 as John Holdren did, but it does go out to 2030. There are very critical and important issues considered in this report that bear on the present discussion. First of all, urban growth will continue at a fairly rapid rate. Rural growth in terms of population is beginning to drop off somewhat. When you break it down further (Figure 4) and look at urban growth in lower and middle income countries versus urban growth in high income countries, you can see the vast majority of the incremental growth in population will be in urban areas in low- and middle-income countries.

Figure 4

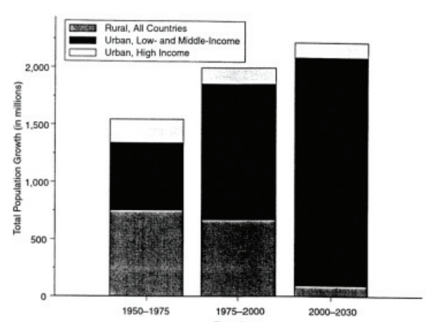


FIGURE 1-2 Distribution of world population growth by urban/rural and national income level. Estimates and projections for 1950–2030.
SOURCE: United Nations (2002a).

This is going to be extremely important, if you look at it in terms of a market for energy technologies. Also, it is an extremely important issue in terms of how these people can progress from a low- and middle-income world by raising their standard of living, which obviously would require more energy on a per capita basis.

Another way of looking at it is in terms of the population impact on new cities. As you can see (Figure 5), by 2015 there is going to be a huge number of new cities, ranging from those with less than 1 million people, but there will also be a substantial increase in the larger cities as well. Nearly 500 million people will be going into cities of less than 1 million. Nearly 250 million people will be going into cities of 1 to 5 million people.

Figure 5

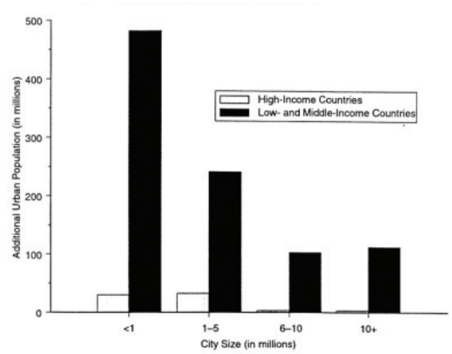


FIGURE 1-5 Net additions to urban population, by city size and national income level, 2000–2015.
SOURCES: United Nations (2002a); World Bank (2001).

Looking at it another way, Figure 6 shows the number of cities with a million residents or more.

Figure 6

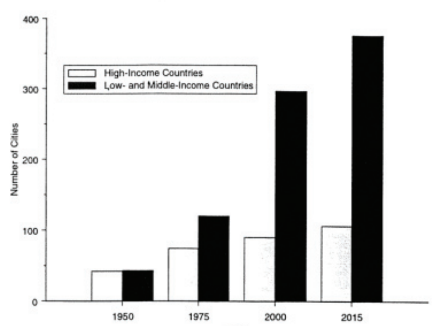


FIGURE 3-2 Number of cities with a million residents or more, 1950–2015.
SOURCES: United Nations (2002a); World Bank (2001).

In 1950, in the high-income countries, there were five cities of 5 million people or more. By 2015 there will be ten of those cities. But in the lower- to middle-income countries, there were only three cities of 5 million or more in 1950. By 2015, there will be 49 cities with 5 million or more. This point is very important. Many of these cities do not have electric grids like we have in this country. So what needs to be done is to apply the third law: If you do not know where you are going, you will not know when you get there. The challenge for these new cities is to design power systems the way they should be designed for a 21st century city, not necessarily the way they have been designed in this country. After all, we started before 1900 in terms of our power system, which, by the way, was the number one engineering feat of the 20th century, according to the National Academy of Engineering.

Getting back to the developing world, let us look at mixing neighborhood grids with a larger grid system for the industrial base. It is easier to deliver reliability and quality for a digital society by using a local grid with distributed generation. Therefore, do not use the large grid model to meet all of a new city's needs. There are ways that this can be accomplished, but it will require working together cooperatively in bilateral and multilateral organizations and using a variety of approaches. It will take the development of policies and incentives to accomplish this. This was considered in PCAST 1999. I thoroughly believe that one of the critical issues confronting society is that, if we do not solve this problem soon, it will be extremely difficult, if not impossible, to handle this much of an increase in urban population in lower- and middle-income countries. We will have to pay the piper in the next 20 to 30 years if we do nothing about this issue.

In conclusion, let me cite two corollaries to the third law. First: "If you are in a hole, stop digging." That one is fairly famous. I have my own corollary: "If you are in a very deep hole, the horizon is much closer to you than you think."

ENERGY AND THE ENVIRONMENT: TECHNOLOGY PANEL

Fuel Cells: Timing and Limits to the Transition to a Hydrogen Economy

Thomas Meyer

I was asked to take the broader conversation that we have been having and focus it on hydrogen and fuel cells. I propose to examine this area and develop some perspective based on timing, limits, and what will be required to make a transition to an energy economy in which hydrogen-powered fuel cells play a major role.

Before discussing hydrogen and fuel cells, I have a paid advertisement to make. The Los Alamos National Laboratory (LANL) is a co-sponsor of this conference. My staff informed me that, "If you go, you better say something about our programs." LANL has developed integrated energy and environment programs as part of a deep and ongoing commitment to the nation's energy security. They include a national fuel-cell resource built on 25 years of R&D expertise; an important effort in carbon management and CO_2 sequestration in collaboration with Fossil Energy at DOE and other national labs; the rejuvenation of a nuclear energy future for the United States in collaboration with DOE and a group of national lab partners through the new Advanced (Nuclear) Fuel Cycle and other initiatives; providing science leadership for Yucca Mountain; and contributing to national leadership in high-temperature superconductivity and modeling of critical infrastructure.

In his State of the Union address in 2003, President Bush declared that the nation should take a major step forward in energy security by moving toward a new hydrogen economy. One of the drivers for such a transformation is environmental.

Given projected increases in the use of fossil fuels, greenhouse gasses, including CO_2, will continue to build up in the atmosphere, reaching levels in the next 15 to 20 years that will threaten the existing environmental equilibrium. With a significant increase in the use of fossil fuels, especially in China and East Asia, we will approach a "carbon wall" where CO_2 levels in the atmosphere will threaten to cause significant and potentially damaging environmental change. One way to ameliorate such effects is with CO_2 sequestration in which gaseous CO_2 is captured and stored as it is produced.

Another approach is to move towards energy sources other than fossil fuels. These include hydrogen from water, solar, nuclear, and biomass to augment our current use of hydroelectric and geothermal power and our increasing use of wind power. We are highly reliant on coal as an energy source with nuclear energy providing 20 percent of the total. Renewable energy as biomass, hydroelectric, geothermal, wind, and solar provide approximately 6 percent of our total energy supply. Roughly one-third of our total energy use is for transportation.

Currently, hydrogen is not a player in the energy mix except on an experimental basis. In fact, hydrogen is not a primary fuel at all and must be extracted from other sources, such as by steam reforming of methane in ammonia production and as a byproduct in refineries. To provide it in the massive amounts needed for transportation or stationary energy applications will demand that efficient technologies be developed for extracting it from other sources. Because of its abundance, coal will become a major hydrogen source with CO_2 as an unavoidable byproduct, requiring that CO_2 be sequestered as hydrogen is produced. On a longer time frame, we will look increasingly to nuclear energy as a hydrogen source by splitting water into hydrogen and oxygen either by electrolysis or the use of high temperature chemical cycles. However, these technologies are not in place. There are viable approaches to using nuclear energy, but finishing the underlying R&D and taking promising technologies past the pilot plant stage will be a significant challenge.

A recent Department of Energy publication addresses the issue of timing and the implementation of a hydrogen economy. On this timeline:

- The Kyoto protocols are met by 2012 with 160 countries committing to limits on the use of fossil fuels.
- By 2020, hydrogen is the dominant fuel for utility vehicles, energy requirements will double in the United States, and 65 percent of the oil that we use will be imported. (There has been real progress in the use of hydrogen-based fuel cells in transportation. The Japanese are deeply committed to this area and the American Big Three automobile manufacturers all have considerable R&D efforts.)
- By 2040, the study calls for no foreign oil imports. (This can only happen if we master the production and utilization of hydrogen. Hydrogen will come from coal and nuclear energy through water splitting and renewable energy sources will begin to contribute significantly.)

- By the year 2050, CO_2 sequestration goals are met, and hydrogen is economically produced from renewable sources. (Utilizing renewable sources on the massive scales required will be a significant and major challenge. For solar water splitting and using the power of the sun, any technological advance must await years of basic R&D.)

There is no guarantee that hydrogen will be the major player called for in the DOE study. There are significant technical and economic barriers to overcome before a hydrogen economy can become a reality. There are technical issues to resolve in hydrogen production, in delivery and distribution, in intermediate hydrogen storage, in the development of a next generation of fuel cells, and in safety codes and standards and environmental impacts.

The capital investment required to create a hydrogen economy will be significant. Production of hydrogen from coal will entail large capital costs including the cost of CO_2 sequestration. Obtaining hydrogen from water by use of nuclear energy will require a new suite of reactors designed specifically for water splitting. Generating hydrogen from renewable energy sources, especially by solar water splitting, may be an ultimate goal, but this is not guaranteed and will require a significant R&D investment. A recent study by GM suggests that the capital infrastructure costs for replacing a petroleum-based distribution system with one for hydrogen will cost tens of billions of dollars.

Finding ways to store hydrogen in large amounts cheaply and safely in a readily available form is an unsolved problem that must be mastered. Storing hydrogen as a gas would require a massive and expensive storage infrastructure. Liquid hydrogen is accessible, but the liquefaction process is energetically expensive. The ultimate storage medium will probably be chemical hydrides, but this is another area that will require extensive basic R&D with no obvious candidate materials currently available.

Hydrogen can be used as a fuel with modifications to conventional internal combustion engines. There are hydrogen-powered buses operating experimentally in some cities that generate hydrogen by electricity and the electrolysis of water into hydrogen and oxygen. A far more attractive approach to extract the energy from hydrogen is with hydrogen-oxygen fuel cells.

Burning hydrogen in air produces water and heat. When trapped in an internal combustion engine, the heat is used to power a drive train. In a fuel cell, hydrogen and oxygen are burned indirectly with the production of an electric current. Hydrogen is passed over a catalytic surface to which electrons flow and protons are released (the anode). The electrons flow to a second catalytic surface where the electrons are transferred to oxygen, which combines with protons to produce water (the cathode). The current that flows between the electrodes is used to run an electric motor in the same way that a battery would.

Fuel-cell technology has evolved significantly over the past 25 years. The technology is understood and has been exploited to power vehicles in technology demonstrations. However, there are significant limitations to everyday use. Current costs are too high, even with mass production. In order for these costs to come down, it will require new solutions to some difficult technical problems. Platinum is currently the catalyst of choice for the hydrogen electrode, but it is too expensive and too rare; new materials need to be found. The current generation of fuel cells relies on expensive membranes to separate the two electrodes and provide a medium for transfer of protons from one side to the other. Membranes that work at higher temperatures are needed to increase the efficiency of the fuel-cell reaction. The catalyst that combines electrons, oxygen, and protons is expensive and leaves much to be desired. Fuel-cell designs that do succeed must be robust, running maintenance-free for thousands of hours for a huge and diverse transportation fleet.

Let me finish by reiterating the promise of a hydrogen future, but also by reminding us that there are many technical limitations that must be overcome to make it a reality. There is the promise of a more secure energy future but not without technological breakthroughs. The emergence of these technologies will require significant R&D investments in photochemistry, catalysis, chemical materials, chemical separations, interfacial chemistry, materials science, new polymeric and ceramic materials, theory and modeling, engineering, reactor design, and systems integration. Environmental gain can only be achieved by coupling hydrogen production from coal or nuclear energy with appropriate supporting technologies on the short term and mastering the production of hydrogen from renewable energy sources on the long term. Finally, the economics must also work with large-scale capital investments in infrastructure and distribution paid for by savings in increased efficiencies and higher costs for other forms of energy.

There is a lot to be accomplished between now and 2050.

ENERGY AND THE ENVIRONMENT: TECHNOLOGY PANEL

The Gap Between Information Technology and Policy

William Wulf

The instructions that came to us speakers said that we were supposed to say something provocative. I am a computer guy; all the people that preceded me on this panel are experts on energy and environment. I beat my brain against the wall for a while trying to figure out how I was going to say something about the environment or energy that would not make me look foolish. So I devised a plan. The plan is, I am going to make the obvious, trite statements about solving our environmental and energy problems; consider that done. Then I am going to talk about a quite different set of issues that have nothing to do with the environment or energy but do have to do with the gap between science policy and society.

The issues I will talk about all have to do with information technology and society. There may well be similar issues in other fields, but because information technology has moved so incredibly rapidly, it has bypassed the normal mechanisms that adapt society to the evolution of technology. I should say that I do not necessarily know any more about the subjects I am going to raise than I do about energy and environment, but, then, you do not either, so I will not look so obviously foolish.

I have collected a list of bad predictions about the computing field, starting with Thomas J. Watson's, "There is a worldwide market for about six computers," through Ken Olsen's prediction in 1978 that no one would ever want a computer in their home. That was just two years before the release of the IBM PC. I think many of you will remember that in 1978 Ken Olsen occupied the same sort of iconic position as Bill Gates does now.

I have thought a lot about these bad predictions by smart, knowledgeable people, and I think the common feature among all of them is that the person making the prediction made an unstated assumption that the future was going to be like now, just better. They failed to realize that large quantitative change in the IT field eventually builds up to qualitative change. A clear example is T.J. Watson's prediction. When he said that there was a market for six computers, computers were only used to calculate ballistic tables. If you take a particular gun and a shell with a particular weight and then put so much gunpowder behind it, how far does the shell go? If that is the application of computers, six does not sound like such an outrageous number!

Of course that is not what we do with computers. Qualitatively what we have done with IT has changed dramatically since Watson's prediction. So I have taken to trying very carefully to look at the assumptions behind a lot of things, and ask whether advancing technology will potentially dramatically change that assumption—make it invalid—and, if so, what are the consequences for society.

Let me give you three examples of societal assumptions that are being blown away by technology. There are a bunch of assumptions that have to do with place, for example. In cyberspace, there is no place. You can try to tie cyber transactions to the computer in which the transaction takes place, but that turns out to break down pretty fast for a variety of reasons having to do with load balancing and redundancy. It is hard to tell where a transaction takes place. It is also hard to tell where a piece of information is stored. If you do try, in fact, it is likely to have a Heisenberg effect—the very act of trying to determine where a piece of information is stored can make it be stored some place else.

The mother of all place-based assumptions is the legal notion of jurisdiction. There are a handful of legal systems in the world, and they are based on very different philosophical assumptions. But they have one or two properties in common. One of these common properties is jurisdiction—the notion that laws apply in a place. Whose laws apply in cyberspace, where there is no place?

About a dozen years ago, a prosecutor in Tennessee indicted a couple in California for hosting a pornographic website. You may recall that the Supreme Court had great difficultly in defining pornography and finally came down on a notion of "community standards." Recognizing that what was considered pornographic in one place might not be pornographic in another place, they decided that whatever the community standards were would define what was pornographic. In the case that I mentioned, the website was, arguably, pornographic in Tennessee but probably was not in California. Who has jurisdiction? Whose laws apply?

There is a similar question having to do with sales taxes. In the United States we have so far dodged the bullet of trying to figure out how to charge sales tax for e-commerce transactions. But the fact is, it is very hard to tell where an electronic transaction happens. We could probably compensate for that in the United States by simply eliminating sales tax and going to a stronger income tax, but in Europe, where there is a tradition of value-added taxes and no income tax, it gets very difficult for information products to try to figure out where they happened and hence where the value was added.

Let me switch to a second unstated assumption. All through our legal and regulatory systems are economic notions that are antiquated. I was driven to distraction watching the Microsoft antitrust trial, for example, because of the embedded economic theories that are even older and, at their core, presume that value is related to scarcity. Gold is presumed more valuable than lead because it is rarer; diamonds are even more valuable because they are even rarer yet.

I am sure you have all heard of Moore's law, but there is a less-well-known one named after Bob Metcalf—the guy who invented the Ethernet. Metcalf's law says that the value of a network is proportional to the square of the number of nodes on it. The larger the number of nodes, the more valuable it is. An obvious example is the telephone network. If there is one telephone in the world, it is not very valuable. The more telephones there are, the more people you can reach, and the more value it has. As a more relevant example, I have Microsoft Word on my laptop. I do not have it there because it is the best word processor available. I do not have it because it is the cheapest word processor available. I do not have it because it is the most bug-free, or the most functional or the most convenient. I have it because I am absolutely certain that I can attach a Word document to an email message and send it to anybody in this room and have them edit and return it. The value of Word is proportional to its ubiquity, not its scarcity. And yet, in the Microsoft trial, I believe the judge did not consider the remedies that would have been most beneficial to society because the law he was working with was based on a notion of scarcity rather than ubiquity creating value.

As a final and quite different example of unstated assumptions that are questionable in cyberspace, consider international treaties. For example, when a country becomes a member of the UN they subscribe to a set of treaties that define the rules about what constitutes fair play in warfare. All of those models of warfare have to do with people throwing physical things at each other—bullets, bombs, etc. Nowhere in any of these treaties is there a notion of what a country can do if they are attacked in cyberspace. There are cyber attacks that could be absolutely debilitating to a country, and yet there is no international legal framework for how they are allowed to respond.

My point in raising these issues was, first of all, not make myself look foolish by talking about something I do not know anything about. But second, I wanted to raise the point that there are a set of science- and technology-based issues that we do not usually include when we talk about science and technology policy. And yet, knowledge of science and technology is absolutely crucial to a successful resolution of them. We need to be serious participants in resolving these issues.

ENERGY AND THE ENVIRONMENT: TECHNOLOGY PANEL

Our Energy Challenge

Richard Smalley

I have been on a personal journey for the past year and half in a search for terawatts to find some happy answer to this problem we have been talking about. I believe the problem is, simply stated, that we have to find a new oil. Oil was, unquestionably, the basis for prosperity for this country and the planet in the last century—particularly the last half of the century. It is very clear to many others, many in this room, that if oil remains the basis for prosperity for the world throughout this century, it cannot be a very prosperous or happy century. For two reasons—first, we will certainly peak in worldwide oil production sometime in the earlier part of the century, perhaps much sooner than we would like to see it; and second, there are vastly more people on the planet who do not consume energy to speak of, that unquestionably will be consuming. Billions of more people, as the century unfolds, will be consuming energy at the rate the top billion do right now. It probably does turn out that we have a carbon wall with immense negative impacts. Should we not find some way of getting around it?

So we need to find an economic alternative to oil. The basis for energy prosperity. Ten billion people on the planet—that is our challenge. I believe this challenge is vastly greater than we give it credit for. Between where we are right now and where we need to get to, we really have to find a new oil. I do not mean a liquid; I mean a technology that makes us energy rich again in an environmentally acceptable fashion for 10 billion people. Between here and where we need to be there is something like ten miracles. The good news is that miracles do happen. I have been involved in physical sciences long enough to see many of them happen: lasers, high temperature superconductors, and so forth. But at the rate that they have been happening, over my life, I am beginning to appreciate the magnitude of the breakthroughs that need to happen. I am not by any means convinced that we will get there soon enough. So I believe we ought to get much more intense about this than we have in the past and launch a major new energy research program to get this problem solved.

So many of you have heard me talk about this, and I want to briefly talk about something that perhaps is new to you. In May 2003, we had a wonderful workshop at Rice University on energy and nanotechnology. We took DVDs of all the presentations, and I have looked at these five times over, listening to everyone talk, again and again. And even the people that I thought I understood what they were going to say, the moment they stood up, I find that even on the fifth time I am learning things. I have walked around trying to imagine at least one acceptable scenario for new energy by 2050, but it seems to be consistent with the bulk of what people were saying. There are certainly three or four different scenarios, but this is an interesting one, and I thought I would just talk about this one and then sit down.

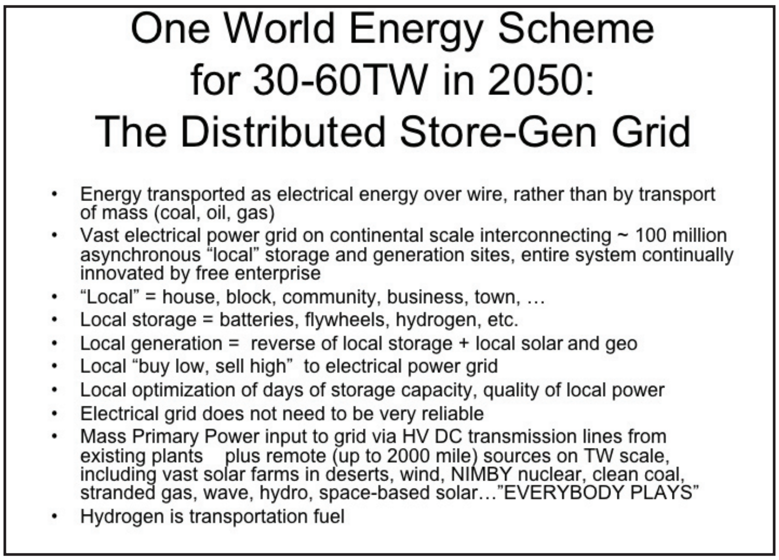
Imagine by 2050, we have hacked this energy problem. What could it look like? But when we left oil as our prime energy driver on the planet, not only did we leave the best, cheapest, primary energy source, this great gift from mother nature, but we also left behind the best possible way of transporting energy over continental and transoceanic distances. Now that we are looking for an alternative way of storing hydrogen, remembering the experience we have when we drive up to a Shell station and gas up with 300-400 miles of gasoline, we realize what magnificent beauty gasoline has given us. About a hundred years ago we found it, or the unrefined predecessors of it, self-propelled coming out of the ground. We got crazy rich on that. Now, we try to find some way of storing hydrogen and there just is none. When we go to get primary energy from the Middle East or somewhere else and bring it across the ocean to the United States, the actual cost of doing that is really quite small. When we leave oil, we have lost that. So we are going to have a future where we will be bringing liquefied natural gas across the ocean, and that is not nearly as efficient, and it is going to be terribly worse when we try to bring hydrogen across the oceans. So how do we transport energy over long distances? Well, I am imagining this scenario that the dominant way we transport energy over long distances is as energy. We do not cart it around as mass and then reconvert it, but we cart it around as electrical energy. And so if you have one word in this scenario to describe this new oil, it would not be oil, it would be electricity. It would not be hydrogen, it would be electricity. That is the key that makes things work.

Imagine for North America, for example, a continental electrical energy grid—all of Canada, the United States, Mexico and down to Panama—which connects on the order of a 100 million local sites. The one characteristic that is most interesting in this scenario about these local sites is that at every site there is local storage. So not only when we left oil did we leave the great primary energy source, we left the best way of transporting it from here to there, we also left one of the best ways of storing it. The biggest single problem of electricity is storing it. And if we are to try to find a way to store electrical energy on a vast scale, as we generally need energy in gigawatt power plants, there are only a few options that you could imagine on that large scale for energy storage. But if you imagine attacking the energy storage problem locally, at the scale of a house or a small business, there must be many more technologies that are accessible. I would rather fight the battle of energy storage locally than on huge scales.

It is fascinating what the impact of this is. If every one of those 100 million local sites has its own local storage—which they have locally decided for their own particular sociological, economical reasons to use a particular technology to give them an hour of buffer or a day of buffer, five days of buffer, however long they have decided to do it—then the energy system starts to make a lot more sense. Then the electrical grid can afford to be fairly erratic. The local sites determine what period of time they want to be buffered. Increasingly, the primary energy producers that put electrical power in the world can just simply dump the power onto the web as the cheapest possible way, and locally, the local storage buys it off the web when it is cheapest, when it is, of course, most abundant. No longer do you have to have a system as we have currently in the United States, where we have almost twice the generating capacity than we use on average because we have to account for the peaks and the lows. Most interesting about this is that the local storage aspect about this system means that it will be very efficiently innovated, continually by free markets. Because when a decision is made locally: "Well, we made a bad mistake when we bought that energy storage technology from Sears because there's a much better one from GM these days." They will agonize over it a bit, but after a couple of years, it is not a huge life-changing decision, it is a little mistake. After a while, they sell off their old unit or trash it and bring a new unit in. It is a small thing, but a 100 million times a small thing gets to be very big. So this allows the electrical energy grid to transform itself, with a time period of a couple of years rather than time periods of decades. This gives you tremendously robust sources.

It is fun to talk about this, but what technology can give you that local storage? You cannot buy it right now from Sears. What technology would be necessary? Here are some of the miracles that we need (Figure1). Just providing the local storage does not completely solve the problem, because you have a primary energy demand here that is going to have to come from new sources. I need one other key technology, and that is I need to be able to transform the efficiency of transporting electrical power over thousand-mile distances, over continental distances. So instead of taking a hundred megawatts over a thousand miles, I need to take a hundred gigawatts over a thousand miles, and do it cheaply so that I can forward the cell power for a couple of pennies per kilowatt hour, 2000 miles away, paying for the entire infrastructure all along the way. If we had an answer to do that, then things start to make sense.

Figure 1



There is a fascinating, wonderful aspect about this. The mass primary power input to the grid from high voltage DC transmission plants can come from existing plants. This is an energy system where you do not have to imagine tearing down everything we have right now and building a completely separate grid. You can start putting this in place right now and have all existing plants providing power to the grid. The value can hook very remote sources including vast solar farms in the deserts, where you are using the local storage to buffer from when the sun's up from when it is down; from when the wind is blowing and when it is not in wind farms; importing vast amounts of electrical power from remote nuclear power sources way out in somebody else's backyard, behind some military fence, where you are absolutely sure there is no nuclear weapons risk associated; from clean coal plants, wherever we have found a place for them where we really think that we can strip the CO_2 away and not have it come back greater than 0.1 percent leakage per year; and the hydro plants. Then the thing starts to actually make sense to me. Of course you still have to solve the transportation fuel problem, and I do not believe there is any clean answer to that aside from hydrogen. But it is fascinating to me to look at this because it tells me the sort of technologies that are necessary to enable this. It is not just making the energy initially; it is transporting it around and storing it.

Let me just stop at that point. I have been trying to leave the global climate change argument to one side, disciplining myself only to use my right arm, my pro-energy, pro-business side, and not the part of me that cares about the environment. I believe this is a much more critical problem than has been given credit for in our political debate. And there is just no answer to this, short of a major new program of a magnitude and sustained level of concentration as the Apollo or perhaps actually beyond that. It may take us a whole generation to get this problem solved.

ENERGY AND THE ENVIRONMENT: TECHNOLOGY PANEL

Discussion

Question: How do other possible types of transportation, which could have a significant effect, greatly reduce our demand for energy and also maybe serve to provide more of a model for developing countries, which now rely on much more simple transportation such as bicycles or walking, etc.?

Kelly: A key factor is something that Larry Papay was talking about—the explosive growth of urban environment worldwide. Are these new cities worldwide going to look like Houston or are they going to look like Frankfurt? The fact is that it is possible to design communities that are delightful, where people like to live, and where you can have high capacity on mass transit. For these new cities, we have the opportunity of not having a built infrastructure but are creating cities almost from scratch. We in the United States have inherited this infrastructure, urban sprawl, which makes a lot of those solutions extremely difficult to apply.

Question: What are the variety of methods for extracting hydrogen and also the potential for Houston to become a hydrogen-based production center?

Kelly: One of the critical issues is, where does the hydrogen come from to begin with? The fact is that it can come from many sources but all of them face tremendous economic problems trying to find some way to compete with the current sources. Right now, the easy source will be from reforming natural gas. With that said, I think that, in terms of finding a new fuel source, the question for hydrogen or any other fuel is whether it can be inexpensive, safe, and transportable. Again, the ideal would be some high tech dog biscuit. I would like a better way to power my laptop at the moment, but I do think it is possible to invent some way of storing hydrogen in a fuel that is safe. Houston sits on the largest natural resource of smart chemists on the planet, and if there is anyplace on the planet that can figure out how to come up with a 21st century fuel, surely it is Houston. The question to these guys is: How to get them organized?

Question: If oil has suddenly gone up to $40 a barrel, an unreasonably high level, what, if any, is an immediate response to deal with a need?

Kelly: Let me just make a comment. The more economically inclined members of the panel will have a more sophisticated answer, but just a simple observation is, unless this price level is sustained and guaranteed, it almost will not have a major impact. It will not provide the incentives for taking risk associated with doing any innovation Price, certainly in the short term, will not lead to needed investment. Incentives for innovation will demand not only market forces but also strong interactions.

If you look at the late 1970s' oil crisis, that is the effect of price—$80 a barrel in today's dollars. But it was not sustained. John Holdren mentioned syn fuel programs. There was no sustaining it, because, as soon as the price of oil came down, a lot of technologies, which in the 1970s and early 1980s were beginning to look extremely attractive, were no longer viable. The carpet was taken out from underneath them.

I certainly agree with the previous two speakers. If the price of oil goes up suddenly and sharply, there will be consequences. There will be adverse economic consequences for all countries in proportion to their dependence on oil. And it is important to understand that it is not actually in proportion to their oil imports. Because there is a world market and one price, your vulnerability to oil price volatility is proportional to how much you will use all together, not to how much you import. If you care about who gets the money, the imports are at issue, but the overall vulnerability is on total oil dependence. It is significant. You can do significant damage to economies by having the price of oil suddenly go to $40-$50 a barrel, but the previous speakers are absolutely right. If there is no confidence it will stay there, there is essentially no impact on industrial innovation and alternatives.

Question: My question is for Dr. Meyer. You might have touched on this in your talk, but you mentioned that hydrogen is not a primary energy technology, and someone might naively ask, why not just cut out the middle man and take out all this time and resources we're investing in hydrogen and put that into looking at a primary energy technology that's clean and renewable? My impression is that the advantage of hydrogen is that it is easily stored and easily accessible and can be converted easily into electricity or into whatever your needs are. Is that a correct impression of why hydrogen is a compelling fuel source?

Meyer: Yes, one of the real driving forces for the use of hydrogen is for transportation. As demand rises and petroleum stocks are depleted, the impact of energy security on national and international security will become increasingly important. It will become necessary to identify a reliable fuel source or sources for transportation. Having said that, petroleum has some appealing characteristics in that it is a liquid that can be pumped, stored, and transported relatively easily. Hydrogen can come from coal, water with nuclear energy, or from a renewable energy source, but extracting it will be more involved technically and demand significant infrastructure investments.

One attractive feature about hydrogen is that a hydrogen infrastructure could be independent of the hydrogen source. A hydrogen economy could evolve over time based on a variety of hydrogen sources. Hydrogen could come now from methane and water electrolysis, followed later by extraction from coal coupled to CO_2 sequestration. That could be followed by hydrogen from nuclear energy by water splitting and, ultimately, by solar hydrogen production. The underpinning infrastructure could well be the same with only the source changing over time.

Question: Since this is a forum on the interface between science and society, I am interested in whether any of the panelists would like to comment on the question of implementation. Henry Kelley went through a number of fascinating technologies, almost a candy store of technologies, including windows. I was trying to think—as I thought about a question—of a case study where you achieve market penetration of something that clearly had great benefits for energy. And so for some of these other things that we are talking about here, have you folks at Kennedy School or perhaps at Rice, elsewhere, really done a study to look at how you make these things happen? What is the implementation side here?

Kelly: Actually, windows are one of the success stories. Something like 40 percent of all windows sold now are double paned with a low coating that came out of a national laboratory study. It sold because it was actually a better product at a lower price. They market them heavily because they are very cost effective.

NUCLEAR ENERGY AND SECURITY

Ernest Moniz

The subject of this talk is nuclear energy and security—a juxtaposition of words that actually can be sent in various directions. Nuclear issues today surrounding Iran offer one way of focusing the mind on a set of specific challenges connected to nuclear energy development—nuclear weapons proliferation, and potentially nuclear terrorism—that might be a good way of framing what I will discuss and then what some of the panelists will discuss.

Iran is a signatory to the nonproliferation treaty. It has a negotiated safeguard agreement in place with the International Atomic Energy Agency (IAEA). It is a complex country, an internal clash of ideas about the country's political and social institutions. They are pursuing a nuclear power program—something we should realize is invariant over time, in the sense that this is not new. This is something that goes back to the Shah. It crosses a rather distinct political boundary, and it is very much tied to issues of national aspiration of a country that views itself as a great nation of frustrated ambitions. The logic of nuclear power in Iran is frankly completely absent. There is discussion about energy security and diversity in a country awash with unused natural gas and with an excellent technology that is not very capital intensive. There is no nuclear power imperative that makes any objective sense. On the other hand, to be quite blunt about it, there is a much stronger logic, in fact, in terms of the nuclear weapons direction, or at least the uncertainty surrounding aspirations in the nuclear weapons regime. You can give lots of factors: the whole Middle East, maybe U.S. troops on both sides, and again this sense of a great nation with a destiny that has not yet been realized.

Now, of course, we know that Iran, in addition to pursuing nuclear power plants, has a rather sophisticated set of activities involving other fuel-cycle activities. The one that has been most in the news recently is the enrichment plant that they have been constructing. The disturbing point, and I think the launching point for a discussion I would like to end with, is that what the Iran situation today highlights is really the shortcoming, or the aging perhaps, of a nonproliferation treaty (NPT) regime that we have had in place for many years.

Countries can certainly come up to the brink of a nuclear weapons capability by pursuing a nuclear power future and, indeed, do so, seeking and receiving the assistance in key technologies from other countries as part of the NPT or Atoms for Peace regime. This fact really was the underlying issue of the considerable and ongoing tension between the United States and Russia, relative to the assistance Russia was giving to Iran's nuclear power program. The fact is, the Russians would argue with some reason that anything they were doing in Iran in the nuclear sphere was quite consistent with NPT obligations, maybe inconsistent with an agreement with the United States, an agreement, by the way, that was in turn inconsistent with a Russia/Iran government-to-government agreement. So it is a real mess of obligations, but underlying is this idea that in the NPT regime as it is today, one can indeed go quite close to this threshold, even with assistance.

Today I will review a few issues of where nuclear power might be going. This will be seen mainly through a Massachusetts Institute of Technology (MIT) study, *The Future of Nuclear Power*, that we published in July 2003 by eight MIT faculty; John Holdren, an MIT graduate; and also, I might add, Chris Jones, a student who got his Masters degree in technology and policy on this study. We should be aware of the absurdities that I mentioned earlier. We should remember that the core issue in nonproliferation remains keeping weapons-usable material, high-enriched uranium (HU), and plutonium under control and out of the hands of possible proliferation nations, and, certainly, especially in the post-9/11 world, sub-national groups, particularly terrorist groups of international reach.

The nuclear power conundrum, in this case, is fundamentally, that there may be strong drivers for a growth of nuclear power worldwide. Climate change is the one driver that brought our group together at MIT for our study. And yet, these materials I referred to, HU and plutonium, are produced by technologies that are shared between civilian and military programs. Enrichment can produce either low-enriched uranium for a reactor or high-enriched uranium for a weapon, and one can process the fuel coming out of a reactor to extract plutonium for weapons. It is only a question of how long you are in there, whether you are targeting military or civilian grade (a long time for HU and a short time for weapons grade plutonium). In any case, today there are massive quantities of such materials in the world. Just in the U.S./Russia orbit, there is, roughly speaking, the order of 1,000 tons of HU and about 200 tons of weapons-grade plutonium. The IAEA's so-called quantities for these materials are respectively 25 and 8 kilograms. That is a lot for weapons. In addition, in the world's civilian programs that have been pursuing plutonium recycling in mixed oxide fuel, there is another approximately 200 tons that have been separated from spent fuel and sit essentially in storage as separated plutonium not very far away from use in a nuclear devise.

So there are three tasks. One, of course, is to protect the materials that currently exist and that are weapons useable. A second is to reduce and perhaps eventually eliminate excess stocks of such materials. The third task is to shape a future technology development and institutions that will avoid creating further problems, particularly while and if nuclear power enjoys a global expansion. On the first protection, I will not say too much even though it is the highest priority immediate task. We have had, since the Russian economy collapsed a decade or so ago, a strong program. Our colleagues, many here from Los Alamos National Laboratory and other DOE labs, play the key role in moving to secure stocks in Russia before they can migrate. This remains a very urgent issue today, and John Holdren has produced excellent reports on the status of these programs. Currently, there is not the need and sense of urgency to actually get the job done, in some sense shockingly, even after the events of 9/11.

A second issue is working down the stocks. Nuclear power has a role here. I would argue that, at least in this realm, perhaps the most successful nonproliferation program we have is taking Russian weapons-grade uranium, blending it into nuclear reactor fuel, and shipping it to the United States. An amount that corresponds to half of the nuclear fuel we use in the United States comes from Russian weapons-grade uranium. That is unfortunately the story, but plutonium is not nearly as rosy. Anita Jones will comment on this. I will just note that there is somewhat of a relevance to the next topic that I will discuss in more depth. The big difference is the HU program, the blend-down program, which fundamentally operates on market economic principles. It makes economic sense to do it, and consequently, it works with all the marginal economic resources. There are lots of political sources keeping the program going. The plutonium program does not make economic sense, and that underlies one of the major reasons why a plutonium recycling future using mixed oxide (MOX) is a very bad idea, and our solution for structuring a technology pathway should in fact assiduously avoid going through that technology.

The third point was that of shaping the future technology pathways and institutional pathways. This is what I will focus on in the context of a nuclear energy growth scenario. First, in the study that we did at MIT, the context was again very much driven by climate change. We set a framework according to a scenario in which, by mid-century, nuclear power would be deployed at a scale that mattered for at least partially addressing the CO_2 problem. Without going through the whole analysis, our view is that a deployment on the order of 1,000 gigawatts or greater globally by mid-century, roughly a factor of three above today's deployment, with a constant market share in electricity production, is the scale to think about. If you look at where that might be, much of the 1,000 gigawatts is not centered in nations where you have the principle proliferation concern. The United States, we have weapons. China, India, Pakistan have demonstrated weapons, etc. There is however, a whole set of countries—Iran, South Africa, Egypt, Thailand, Philippines, and Vietnam—who are on a track for nuclear weapons. In the end, we need regional strategies—a Middle East, Southeast Asia, Northeast Asia, and South America strategy for dealing with proliferation and the expansion of nuclear power.

A key issue with regards to the expansion of nuclear power is economics. I think it is important to just give a summary of our results. In performing a merchant plant model evaluation of the levelized cost of nuclear, coal, and gas as the prominent base load electricity services for new plants, what you can see is that based upon experience—historical experience, not engineering analysis and optimistic statements of the future—nuclear starts out with an unimpressive competitive position: around 6.7 cents per kilowatt-hour versus 4.2 cents for coal. Gaining enough confidence to reduce the financial risk factor in the markets can bring nuclear into competition with gas and coal. In addition, if we ever come around to internalizing the costs of carbon emission (tax, cap-and-trade, you name it) at $100 per ton of carbon, and even at $50, you can have a pretty significant impact, especially on the coal costs going up. When you take that into account with the fact that the motivations in different countries may not be strict market analysis in a merchant plant sense but may include energy security arguments or other national security aspirations, what I would say is certainly nuclear power cannot be dismissed as a potentially spreading technology in many of the countries that we discussed earlier.

Those costs are for an open fuel cycle, that is, when a spent fuel is recycled and shipped towards geological disposal eventually. Today, various countries (France, Japan, and others) are actively pursuing the recycling of plutonium into new fuel. Originally, the argument was the energy value in plutonium should be captured. Japan and France, for example, are rather resource-poor countries, and they had a stronger imperative in their view towards these energy security arguments for nuclear power. For the moment, let me just say that the MOX fuel cycle is viewed as especially bad because it makes available an operation to separate weapons-usable plutonium. We do however, in the report, make a contentious recommendation that, despite those statements, we advocate a significant analysis and basic research program on advanced fuel cycles that may or may not be competitive in 50 years or more—for example, if uranium resources are somewhat less than we expect, or because the competitors have other problems. In addition, the argument now given for these closed-fuel cycles, including the fuel cycle in France, is based on a different factor, and that is the management of nuclear waste. I only want to make one point: As you look along the years after discharge, you see this profile slightly oversimplified. The century time scale is dominated by fission products. The millennia-and-more time scale is dominated by actinides and plutonium and others. The argument now for recycling is that you process the spent fuel to remove these actinides, put them back into the reactor to refission them, leaving yourself with a waste profile that has had its scale reduced largely to the century time scale, and that is the idea in terms of now going to these more expensive recycling approaches.

Our study concludes that although it is indisputable that if you do remove those actinides and you do in fact change and somewhat improve your prospects for very long-term waste management, we argue that the benefits are not overly compelling, particularly when the net analyses is made of environmental impacts. We also conclude that there are alternatives to be pursued that can gain you equal or greater factors. One example I will show, to please our Los Alamos colleagues, was done by Grant Heiken. For example, we could revisit the old idea of using very deep boreholes. It turns out, even in a very conservative cut, attractive geologies are virtually everywhere you need them. Frankly, we stopped doing research on waste management a long time ago, and we feel that it is really important to resume that.

That finally brings us to the proliferation argument. Although I assure you I will come back to why that discussion was relevant. We have a number of recommendations in the report about institutional issues, upgrades of safeguards, and the importance of the additional protocol, which would give the IAEA the right to go in and look at undeclared sites in various countries.

Let me focus on one issue: The overall architecture of the nonproliferation treaty regime pushing forward the global growth of nuclear power. I will start by pulling in the threads of the United States, Russia, and Iran. In 1999-2000, we worked on something with Russia that provided the template that I will discuss. It was about resolving our differences with regard to their collaboration with Iran. Russia was completing a power plant that supported additional fuel cycle activities that were problematical. The program that we pursued had various elements. One was that Russia would have a moratorium of a minimum of 20 years on separating any further plutonium from its reactor fuel. I want to stress not a renunciation of the use of that material but a moratorium to buy time for decades. Second, there would be an inventory of plutonium and enhanced protection measures. We would support them in joint, advanced research and development, both on geological isolation and on advanced fuel cycles. We would move down the path of international spent fuel storage.

The Russians were very interested in bringing spent fuel from other countries there for a substantial fee. They viewed it as a $20-billion business. We viewed it as a proliferation benefit to get plutonium-bearing fuel to Russia, which is a weapons state. In addition, there would be a moratorium on the Iranian collaboration where we would stop harping on completing the Bushehr reactor. I remind you, the reactor is not a part of the proliferation risk. It is really what goes on before and after the reactor—enrichment or reprocessing. If you want electrons, have a reactor with appropriate safeguards. Russia would not support Iran in any work on the fuel cycle, except maybe some small research reactors. Russia would supply fresh fuel for their reactors and return the spent fuel to the international spent fuel repository that we would be supporting them to do. That program was actually viewed as quite attractive. In the end, the clock ran out in the administration; it did not quite get there.

Let me first emphasize the link between waste and nonproliferation. This scheme had the spent fuel moving from country A to country B, country B being Russia in this case. So resolution of nuclear waste issues can be very important for opening up options for a new nonproliferation regime. Indeed the synthesis of this, for a broader application, is that rather than focusing on the NPT separation of states into the original weapon states and others, we might want to evolve in a growth scenario to a situation in which essentially states who do not pursue fuel cycle activity have all the help and support they wish in terms of reactor construction, design, operation, training, etc., but no fuel cycle activity. What do they get for it? They get to avoid the large infrastructure costs. Lots of countries do not build automobile plants. They buy automobiles to go somewhere. They can buy reactors or build reactors to provide electrons. They do not have the owner safeguards that we would advocate that would be applied to those fuel cycle states in the future, including the United States. And they do not have a waste management problem. Their spent fuel goes away, and of course they have a guaranteed international supply of fresh fuel.

These ideas, also ones put forward by others, are gaining some currency. Let me close with a few other problems in terms of how one can move on this very aggressive program over the next 10 to 20 years. The first question of course is: What is the U.S. position for leadership? Frankly, you cannot do this program if the United States is not both leading and participating in all parts of the program. The Bush administration has both pluses and minuses for moving forward. Certainly on the plus side, its energy and counter terrorism strategies are very well aligned with these kinds of initiatives. The energy strategy explicitly talks about commitment to our quarter-century-old principal of not supporting at least plutonium accumulation, but it advocated doing research and development on advanced fuel cycles. If we are not participating in this program, frankly at a minimum as a lure to other countries to play, it is not going to go anywhere. Just saying no in 1977 did not prevent the spread of the plutonium MOX fuel cycle.

On the minus side, certainly a lot of the nuclear weapon body language (bunker busters, Comprehensive Test Ban Treaty issues, etc) would not be viewed as a positive starting point for these negotiations, nor would a sporadic unpopularity at the moment in various parts of the world. But there are other players with whom we could work. Japan and France, for example, as big MOX players, must play in this game. France, Germany, and Britain have just had an interesting dialogue with Iran, perhaps producing an agreement to the traditional protocol. Russia is a central player. They have materials. They have technologies. They have a relationship with Iran. We have just added up most of the G8. The G8 has positions out already on nuclear weapons materials and on counterterrorism. They have a foundation, potentially, if the United States could organize it, to move forward on this adjoined program in which reactors are understood not to be the principle concern, fuel cycles are. We establish the mechanisms for providing the fresh fuel guarantees and the spent fuel return. This is not trivial; that is why waste is critical, and why we need to commit to working with others, on what would undoubtedly be a long-term research-and-development program on advanced fuel cycles in which we all may have very different expectations about what the result may be. But the key is that—and this is where I think we could conceivably work with the French, the Japanese, and others—like the Russian program, we do not have to say: In the future, you will not use plutonium, you will not recycle actinides. We can wait and find out. What is really important is getting on this pathway, reestablishing the framework, and getting at least a moratorium on any expansion on the use of these actinides.

So that is where we need to go. Time is critical. This is the year before the election year, and frankly, if this kind of program is not moved out literally within months, we are going to have a pretty big gap before we can pick it up again. There is interest in this; we will see what happens.

NUCLEAR ENERGY AND SECURITY

Discussion

Question: Are there technologies out there, which will really vastly diminish the risk of proliferation?

Moniz: First of all, let me clarify that as far as reactor design goes, our view is that, for at least a couple of decades, the reactors you see today are the only game in town. Then in the intermediate term, we hold out some degree of optimism on gas reactors. On proliferation grounds, many would argue that the gas reactor does have some proliferation benefits because of its fuel form. The fuel is encased in carbon materials. Although that is not an absolute guarantee against proliferation for sure. For the longer term, for the closed fuel cycles, our view is that the MOX fuel cycle is an absolute disaster if it starts to spread beyond its current locations. It may already be a disaster. However, the real discussion for the future is less about the reactor per se, than about the fuel cycle design. For example, if a popular model is a fast spectrum reactor with a fuel form, maybe a metallic fuel form, which is then electrochemically processed (non-aqueous) in a way in which plutonium and the actinides never get separated, and they stay within a closed environment. You still have the question of tweaking the system, etc. I personally believe that this carbon system could be designed in a way with appropriate safeguards that would make it very difficult to at least surreptitiously break out. I also believe this kind of fuel cycle would look to have a cost that would just blow it out of the water as being competitive with anything. I am willing to invest some money for 20 to 25 years to find out in the context of these other things happening.

Question: You mentioned that the countries of concern really do not have high electricity usage, and then there are these regions that we can consider thinking about around the issue of nonproliferation. Could you speak a little more, briefly, about that? When you say “regions,” do you mean Middle East, North American?

Moniz: As you know very well, in the report there is an appendix about projected growth and nuclear share in various countries. There are four different types of countries, roughly speaking. When the variable one uses is kilowatt-hours/person/year, clearly there are the advanced countries, which are typically in the 6,000 to 15,000 kilowatt-hours/person/year range. The United States, right now, is around 13; Europe is around six or seven. In certain countries, projected growth will increase at a fairly modest rate in terms of electricity production.

Then there are the advanced developing countries. China would be a good example, with good management of the country's business; they have every reason to expect very substantial growth. For example, in our projections, we had a growth in China's per-capita use of electricity. Today they use around 800 kilowatt-hours/person/year, which is predicted to increase to 4,000 in 2050. This can be achieved with a reasonable amount of investment. Last year it grew by 10.5 percent. A third group of countries, India being a good representative, is very unlikely to experience this amount of growth. They can credibly reach 4,000 kilowatts/person/year, but they might reach half that in a country which will then be 1.5 billion people. In those two groups, you see lots of candidates for this kind of nuclear power expansion. There is a fourth group of countries, many of whom are in Africa, which you cannot imagine having the investment capacity to reach a large amount of electricity per capita, nor do we consider them to be credible candidates to enjoy this nuclear power expansion.

Question: If we went to the kind of scenario you laid out 2050, with that kind of power production tripled or quadrupled, how many Yucca Mountains are you looking at, assuming you do not get your bore hole ideas developed by then? Does a lot of that have to go to Russia, just by the nature of the amount of it? We are not going to build a lot more Yucca mountains in the United States, I assume. The final aspect is how reliable would that storage be in Russia. We have issues with missile proliferation with Russia that preclude certain space cooperation today that we are not proceeding with.

Moniz: We have ongoing issues with Russia. Nevertheless, I would turn that question around. Would you prefer to have it in Iran or in Russia? We could also draw some names. I personally do not see what the great residual risk is in having it in Russia. Maybe I will, after they get rid of the next 1,000 tons of HU.

Number two, there seems to be quite a bit of receptiveness to have this arrangement under some kind of international supervision, and many think that is an essential issue. Whether it is done through a private mechanism, there are these trust arrangements that have been proposed, or through government mechanisms with some explicit international monitoring, this time issue is important because, in light of the proposals, even if Russia receives a lot of this fuel, and the United States has consented rights over 75 percent of it roughly, there could be a condition, and in our view should be a condition, that any reprocessing would not occur for a long time. There are lots of technical reasons in support of it, but also other reasons. They certainly had no objection to what we were discussing in 1999-2000, because the logic was that if we were going to get together on this big research and development program for the fuel cycle for the future, why not wait and find out what it is first? So, I think there were a lot of safeguards in there. I think net, it is clearly a benefit and $10 to $20 billion could also be used in some positive ways.

Question: The argument that people propose is not just that the lifetime of danger is much less but also that the volumes are much less, and given how politically hard it is to find anywhere to stick this stuff, doesn't that buy you awful lot less of volume?

Moniz: The issue of designing a repository is not driven by volume or mass; it is driven by heat and ultimately by transport to the biosphere. In fact, there has been a lot of pure and simple deception along these lines. I will give you a very current example in the United States. The DOE in January sent to the Congress a proposal to build reprocessing and pilot plants starting next year, so that they would be built and in operation in 2015—a 2,000 ton/year reprocessing plant. To give you a scale, a 2,000 ton/year reprocessing plant means handling essentially all the reactors in the United States. The argument given was, if you do that Mr. Congress, and you raise the limit of Yucca Mountain to a 120,000-metric-ton capacity, you would never have to face a new repository decision, because the mass will be so much smaller. My question to the members of Congress and the DOE was: How long do you think that argument is going to last? You have reduced the volume and the mass by taking out the uranium. The uranium was not the problem. Certainly as far as heat-load goes, for century scale, the fission products have not changed at all. Tell me how many kilowatt-hours thermal you produce, and I will tell you how many fission products you have. So heat load, those kinds of things, are unchanged by this kind of arithmetic. The fact is, that the Waste Policy Act, in setting the Yucca mountain cap on mass, chose a largely irrelevant variable. It does not matter, as long as you always run the same fuel cycle, because then everything is more or less proportional. But if you change the fuel cycle, the variable is ridiculous. I think the Natural Resource Defense Council (NRDC) would have seen that one in less than four years.

NUCLEAR SECURITY: PANEL

Expertise, Literacy, and the Capacity of a Nation

Anita Jones

I was asked to respond to the MIT report *The Future of Nuclear Power*. The report addresses the potential deployment of nuclear power at a scale that would make a material difference in terms of reducing the carbon that will be produced in future energy generation. It discusses proliferation and policy. Other key elements that the report calls out are the costs, the technical processes, the safety issues, the waste handling, and the issue of public acceptance. I want to make some observations that are complementary to the report.

Nuclear power generation unavoidably relies on a sophisticated technology-based industry, and all technology-based industries require a sustained flow of well-educated technical and management people that understand the technology upon which the industry is built. Those people need to have the expertise and knowledge to design, operate, and troubleshoot plants as well as the knowledge to understand the physics, information technology, and other engineering aspects that are relevant to innovation in the industry. Others need to be expert in the related technical policy issues. Consider what has happened to that crucial human infrastructure over the last couple of decades.

First, in education, I will use the University of Virginia (UVA)—which is where I teach—as an example. UVA closed down its nuclear engineering department a couple of years ago. What happened over the last few decades was that the numbers of undergraduates interested in the topic rose and then fell quite dramatically, in tune with public attitudes. Graduate students are more single-minded, they continued to have interest. But then graduate students in nuclear engineering declined. In the late 1990s, the department had four graduate students and six nuclear engineering faculty. This is not a basis for sustaining a viable research and education program. Undergraduate courses had lost their student attendance.

There was strong support in the faculty for the existence of the nuclear engineering program, because of the belief that this technology was really important to the world. The faculty wanted to contribute. We wanted to have a piece of that action, but it became unsustainable. There are substantial costs, and there are real opportunities lost if a university sustains academic programs for which it does not have adequate students or research funding. So, in the end, after much discussion and soul-searching, UVA closed the department. This same scenario played out in other universities as well. Most importantly, as these research programs closed down and the education programs closed down, the nation lost the pipeline of new technical experts both at the graduate and undergraduate level.

Closing the UVA department involved also closing one of the last few remaining university research reactors. We scrambled like crazy to find outside uses in order to keep the reactor open. Even with the kind of research budgets that you have seen on several slides at this symposium, we could not find enough business to make a rational argument for keeping the reactor open. That reactor is now decommissioned and closed. It will not come back easily, especially at a university that went through the trauma of closing down such a site and such a department. This has occurred at multiple universities, and a crucial portion of the human infrastructure needed to for nuclear energy has been lost to this nation and the world. The education pipeline at the undergraduate and graduate level and the faculty researchers are essentially depleted. Both are needed in order to have a strong capability to support nuclear power generation.

Now, I will turn to industry. I recall hearing Richard Meserve, the chair of the Nuclear Regulatory Commission, say several years ago that there were 40 nuclear power operating companies. He predicted that in five to ten years, there would only be ten companies. Industrial capability is following the same path of decline as the educational capability, essentially for the same basic reasons. Because of the hundreds of plants that exist worldwide, there is still demand for operations and, therefore, that expertise declines more slowly.

The operational experts are retiring and they are not being replenished at a high level by the universities. Few plants are being designed and built. There is little demand for innovation in design. Prime contractors with the ability to design and construct nuclear power generation plants turn to other kinds of projects. Designers retire, turn to other projects, and most certainly lose their fine edge.

I have observed similar effects in the military-industrial marketplace. When design and construction of a very specialized kind declines, one of the most precious commodities that is lost is the second-tier suppliers. The prime contractors rely on the engineering expertise of its second tier to provide highly specialized, sometime arcane, services and component products. When their expertise is so specialized that they cannot turn to other markets to sustain that expertise, it is unavoidably lost. The prime contractors often have alternative market options open to them and they can adapt to, and even survive, a lull in business. But the second-tier suppliers may not have viable market choices to sustain their business and thus their capability.

So, if you consider the people infrastructure within the prime contractors, the second tier industry, and the nuclear engineering education enterprise, we have a lot to rebuild if we want to accomplish the recommendations of the MIT study. We appear to be far below critical mass of human expertise along several dimensions.

So I would like to make three observations. Observation number one is: The human infrastructure has declined. A sufficient population with current expertise and knowledge would have to be rebuilt. It cannot be rebuilt over night. So, if we want to head in the direction recommended by the MIT study, there needs to be increased investments in nuclear education and research in order to rebuild the nuclear engineering education enterprise in order to begin to produce the educated students, particularly the experts who could innovate and build genuinely new plants.

Observation two relates to technological literacy of the average citizen. The MIT study touches on public acceptance. Nuclear issues are hot buttons for the citizens in many countries. “You are not going to put a plant or a waste site in my backyard.” In fact, the public today is, by and large, negative on any engineered product that radiates, even when that radiation is below ambient—the radiation to which a person is exposed as they move through daily life. Even when ambient radiation is pointed out, the response remains, “I don’t care. I don’t want nuclear plants or waste sites in my neighborhood, my town, my state.”

Nuclear energy is only one of a few technologies for which the improvement of technological literacy of society is particularly important if we are to have all possible technology options. On the topic of nuclear power, one is fighting human nature. It is human nature to focus on the immediate, the short-term, and especially upon immediate rewards. Increasing the nuclear power generation capacity is a long-term process.

One thing I found interesting in the MIT study is that their poll showed that even the environmentalists who were concerned about global warming had not made a connection between global warming and the carbon-free nuclear energy generation. If the environmentalists do not make that connection, how can you expect the rest of the citizens to make that connection?

In addition, the technological literacy challenge to increasing nuclear power generation became much more complex on 9/11. Before that, people worried about the safety of the plants. Today, proponents also have to argue that a nuclear power plant will not be a target that can be exploited by terrorists. In preparing for this talk, I ran across the following quotation from Martin Luther King: "Shallow understanding from people of good will is more frustrating than absolute misunderstanding from people of ill will." He was talking about a different topic, but it occurred to me that it was apt for today's discussion. So, observation two is that we need to improve the technological literacy in the area of nuclear power generation, as in some other areas. The title of this symposium is "Bridging the Gap between Science and Society." The gap between the understanding of scientists and engineers compared to the understanding of the general public is a gap of very deep concern.

My last observation is: There is a new tool in the arsenal. For nuclear power generation, one can apply analytic models and simulations. There are economic models, environmental models, plant operation models, as well as models for the entombment physics, deep borehole geology, and the entire end-to-end generation process. Models and simulations are tools that can help keep open the nuclear-power-generation option. It is a tool that is particularly useful in policy debates. It is a tool for which there has been dramatic improvement over the last couple of decades, and there will be consistent improvements certainly in the future. So automated models and simulations are a tool to be wielded and wielded effectively.

There were some exchanges earlier today in which speakers expressed either complaint or frustration that scientists require a multitude of alternative scenarios (for example in the exploration of issues related to global warming). Scientists do not form a consensus around one predicted scenario. We end up with bounds on what might be future temperatures in global warming. Some feel a need to compress the spread in order to derive a more compelling argument of future predicted temperatures for the public and to inform policy discussion. I wish to differ with that view. I think that the objective should not be to compress ranges artificially. Alternative scenarios are useful, partly because what is important to different portions of the broad audience is different. We need better technological literacy so that the public appreciates that when scientists make predictions, they have wide ranges for good reasons. Artificial compression of ranges will result in some wrong answers and it will undermine the scientific and engineering community's ability to speak out on technical issues. Again, we return to the need for greater technological literacy in the general public for discussion on nuclear power generation and on global warming—just to chose two topics.

In closing, one can think about the prospects of increased nuclear power generation from six perspectives. The *optimist* says the glass is half full. The *pessimist* says the glass is half empty. The *realist* says that the glass is broken. The *experimentalist* says that the system is too complex, and it is hopeless to try to model or measure it. The *theorist* says that this is such a complex engineered system nothing can be derived or proven. None of the five offer a great deal of help. The last of my six is the *theologist*, and the theologist says, "God rules. And God gave us an opportunity for carbon-free generation. It exists. The challenge is for the human race to take advantage of it."

NUCLEAR SECURITY: PANEL

Gregory Canavan

I was asked to speak on weapons testing during the Strategic Defense Initiative. Since parts of it were executed before some of you were born, it might be helpful for me to provide a brief introduction. In fact, if you do not mind, I would like to discuss something that may seem an aside, but might help put the task I was asked to discuss into context.

Command and Control Loops for ISR and Engagement

There has been a major reorganization of the Department of Defense (DOD) over the last few years, which has caused me to spend a lot of time drawing command and control systems for old friends who are still in the service. There are certain principles involved. You have a commander and you have two loops (Figure 1).

Figure 1

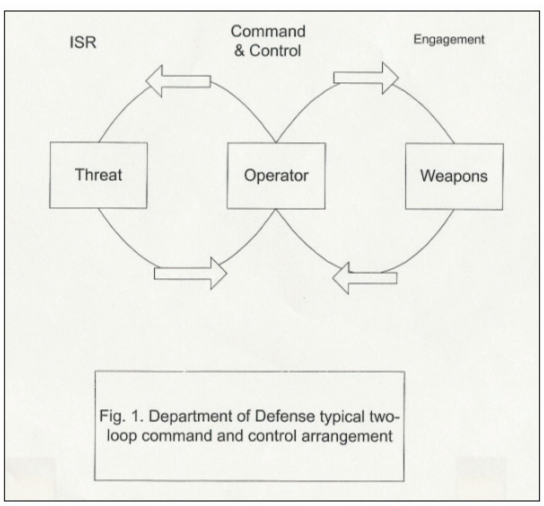


Fig. 1. Department of Defense typical two-loop command and control arrangement

The left loop is called the ISR loop, which uses various sensors and sources to get intelligence surveillance and reconnaissance (ISR) on the opponent. The commander sends out airplanes, predators, or other sensors to get information. Then he decides what to do and sends his strike assets out. They engage and report back on their success. Based on that report, the commander decides whether to take another look, move on to something else, or make another strike. That is to the essence of military command and control. Those same principles apply to command in other areas.

I have been drawing these loops for 40 years, but they go back much further. In World War II, the air-tasking order that gathers ISR and sends the planes out took about 72 hours. At the beginning of Vietnam, when I was first involved, it was still about 72 hours. It became faster by the end of Vietnam, but by the time of Bosnia, it had slowed back down again. It generally accelerates during conflicts and decelerates between them. At the beginning of Afghanistan, it was about 24 hours; by the end, it was down to six or eight hours. In Iraq, the starting tasking order delay was six to eight hours. That was deemed unacceptable, so by Herculean efforts, the average cycle time from weapons request to delivery was reduced to five to ten minutes.

In going from World War II to Vietnam to today, the real change that has made the military so much more efficient is not the machines but the ability to execute this cycle much, much faster. In modern war, whoever turns the cycle the fastest wins. That lesson also holds for other organizations.

Application to Policy

There is a lesson in this for policy as well. When I worked for the chief of staff in the Pentagon, in the DOE, and in the White House, I found there were analogous processes for command and control operations there (Figure 2).

Figure 2

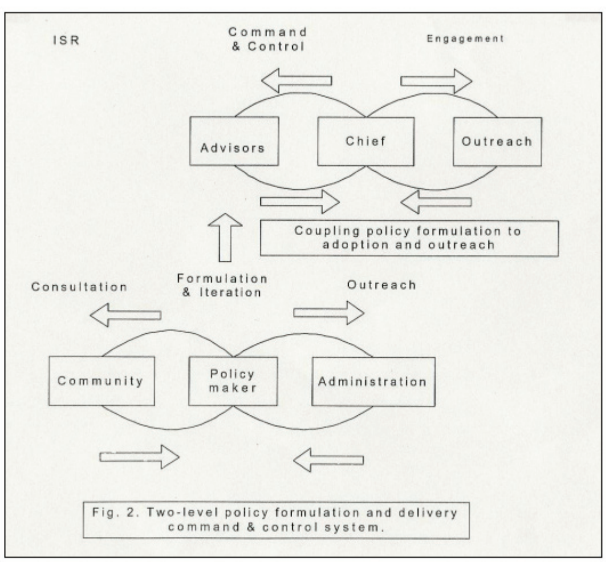


Fig. 2. Two-level policy formulation and delivery command & control system.

What does a policy maker do? He goes out to give speeches, listens to his friends, and argues with co-workers to find out the legitimate parameters for a given problem. Once he has done that, he has to go to his colleagues in government, his several bosses, and to outside organizations to win support for the policy he has formulated. These three steps follow those in the C2 loops described above rather closely.

There is a useful but imperfect analogy to the military process described above. Policy is not war. It is but one input to the decision-making process that goes on up at the top level. The diagram is drawn this way to remind you that it is important to understand whether you are making or executing policy. If you are in a policy loop and act as if you are in the process of executing, and there are others who are trying to formulate a national program, that jams the system up. Some things of interest in this meeting have been jammed up for at least the 30 years for which I have been involved. With that preamble, I will turn to the assigned subject.

Application under Eisenhower

The process illustrated in the figures above is generally attributed to President Eisenhower. He developed it as a way of leading the coalition forces in World War II. Big science was born in the war but did not penetrate the White House or other serious advice vehicles. President Roosevelt had a narrow circle of advisors, none of whom were scientists, and President Truman found them stuffy.

President Eisenhower knew how to use this system. He had good success with scientists advising him in World War II, so he used this system in the White House to good effect. President Eisenhower not only established a science advisor but he also established a science council and made science an important part of White House decisions. He also put science and senior scientists into all the important agencies—Department of Defense, intelligence agencies, etc.—which he used to help build a consensus, not only on overtly military systems but also on the U2, Oxcart, and Corona spy systems and satellites that his successors used to get through the Cold War. President Eisenhower was regarded by some as a do-nothing President at the time, but as his use of scientific advisers has become public, it has become known that he built both the process and the systems that served the presidents after him very well.

Nixon Administration

When a member of the President's Science Advisory Committee (PSAC) opposed the

President on technical issues, Nixon disbanded the PSAC and fired all the scientists he could find in the White House. That left a void, which was partially filled by the one scientist left who was mislabeled and hence hidden. But after a while, piles started growing with scientific issues nobody knew how to answer, so he formed an underground railroad of helpers who would come in after hours, shuffle through in-baskets, and to try to sort them out. That gave a number of scientists an opportunity to get a little experience in applying pseudo-policy in the White House. In Anita Jones's interesting analogy of itinerant workers, they were the scientific janitors who came in about the same time as the real janitors, although they were paid less.

Because President Nixon got rid of his scientific staff, the scientific issues on which he needed to formulate policy—the oil embargo, the energy plan, the ABM system, etc.—were handicapped from the start, which led to serious problems in implementation later. The lack of a healthy ISR system to find out what was going on in the agencies and public and to coordinate them frustrated the major scientific issues of Nixon's White House.

Carter Administration

I served as a White House Fellow with the Office of Energy Policy Planning, which was basically 16 guys in the back room designing the Department of Energy, making an energy plan, and announcing it to the unsuspecting world. Given the disparity in size between that of the staff and that of the problem and interest groups, it is not surprising that the loops did not close well, so the new department's advocacy was not compelling. As a result, we got both a sub-optimal energy plan and a large Department of Energy, which was in some ways the worst of all worlds.

Reagan Administration

I worked for, but not in, the Reagan White House as part of a small group headed by David Packard to study the transition from an offensive to a defensive military balance. The group that formulated the policy was small but did a competent job. At that point, I was younger and still had a good bit of hubris. When it was time to write the report recommending what the President should do, I drafted a number of specific recommendations and then added an admonition that whatever was done should be done quietly, as missile defense had a lot of enemies who would take exception to any strong statements.

The President did not pay any attention to my suggestions, but the result probably would have been the same either way. His unilateral action violated the comments above about how the ISR loop should work, but because he was such an effective speaker, he got a useful level of support for the policy nonetheless. President George H. W. Bush used a more typical process to build broader support for the programs, which were, however, killed by the Clinton administration for reasons of arms control policy that reflected the differing beliefs of a different administration.

Testing during the SDI

There were three main pieces of testing for the Strategic Defense Initiative (SDI): nuclear, non-nuclear, and space-based. Nuclear testing got the most publicity. People wrote books and articles about it. I found it amusing because the operation, which was required to go from what happened to what was written, was essentially a mathematical inversion. The part that received the most discussion was the nuclear-pumped X-ray lasers, whose fundamental problems were raised in the Packard committee, were understood long before SDI, and were resolved quickly through a joint experiment between Los Alamos and Livermore, the two nuclear design laboratories, in one of the most cooperative efforts executed between the two labs.

Livermore was doing tests on X-ray lasers; Los Alamos got permission for two scientists to add some diagnostics to them. They found out what had been wrong in the analysis of the tests, and the X-ray laser was put back in R&D. The X-ray laser never impacted any of the DOD or White House decisions, but it taught me an important lesson. Be careful about what you read—particularly about politicized programs—especially if the information or writing is based on leaks that come from people who feel terribly aggrieved by the process.

Weapons Testing

While there are philosophical and political answers for why nuclear testing is needed, the main reason is that nuclear weapons still involve significant uncertainty. When I was involved, I found it easy to go back and forth between nuclear weapons, turbulence, and climate modeling, because all three involve intrinsically unstable and ultimately fully turbulent flows, for which we have no first principle understanding. One cannot claim to understand turbulence in weapons better than in the climate, because at heart the two phenomenons are intimately related. Absent fundamental understanding, sometimes it is necessary to test. That is true even for modest modifications of designs that have been tried before, because of the narrow parameter space in which they have been shown to work reliably and not work unintentionally.

If testing is important for confidence in small variations about developed designs, it is essential for new designs such as the small, clean weapons suggested for precision strikes on deep underground targets. Small fission weapons that could suffice for some might not need testing, but that is not the case for the improved weapons targeting deeper chemical and biological factories and stores.

I spent a decade on offensive weapons—roughly three decades trying to eliminate them—and continue to work on that now. However, nuclear weapons remain the *ultima ratio regina*. The main thrusts of current nuclear programs are to certify existing weapons for as long as possible without test, to develop a first principle understanding of them, and to develop new designs that could permit changes without test. But as long as nuclear weapons remain an essential element of our defenses, it will be necessary to keep them safe, reliable, and relevant for emerging threats.

The difficulty of science advice has increased over the last four decades. Public confidence in its contribution was high in the Eisenhower and Kennedy administrations but was eroded by Vietnam, whose lingering effects can still be seen in newspaper articles interpreting the Gulf Wars in terms of its metrics. The ABM debates of the 1970s are largely forgotten, but their polarization of the scientific establishment was evident in SDI and is still echoed in discussions of the Missile Defense Agency. Dissents in the Carter Energy Plan are reflected in mistrust of this administration's energy, environmental, and climate research. In science policy, as in life, friends come and go but enemies are forever.

The resulting splits are not so much between researchers and policy makers as between policy makers and the public—or lobbying groups that declare themselves to be the conscience of the public on a single or narrow range of interests. Confrontations between such groups and public policy makers have reduced confidence in institutions. Science advice was once the gold standard; now professional advisors and institutions are characterized as lobbyists for science, and the scientific literature is accused of bias. Critics only have to point to areas of disagreement to undercut the value of scientific advice. The result is that science has partially been replaced as the arbiter of technical issues by newspaper reporters—or by 15-second sound bites by talking heads on TV.

Some of attacks have swung too far, so there are nascent reactions in energy, nuclear waste, weapons, defense, the environment, and climate. But achieving the level of balance and civility needed for science to produce the understanding that can build support for legislation on national problems will require significant effort. It must include individual scientists becoming involved more strongly than has been the case—rather than counting on interest groups to work for them—and effective knitting-up of residual divergences by future advisers.

The number of major issues in which legitimate differences exist suggests consideration of some system patterned on the law courts for resolution of technical issues. While scientists generally express concern about interacting with lawyers, it is worth noting that when the Supreme Court decided the recent presidential election, its decision was promptly accepted and implemented. Having one's argument evaluated by a panel of senior and respected scientists could be more satisfying than having it evaluated in the evening paper or television news.

Effective Advising

It is suggested above that there is a strong parallel between effective command and control as executed by the military and that is needed for effective science advice at the national level. That was clearly the case in the Eisenhower and Kennedy administrations because they used essentially the same process. When the Nixon administration eliminated the advisor, and with him the whole upper level, it significantly impaired the decision-making process. The Ford administration restored the advisor more than the mechanism, but the relationship of the advisor to the President produced a workable process. The relationship of President Carter to his advisor, and through him with the technical community, produced an effective process. The preferences of Presidents Reagan and Bush and the personalities and backgrounds of their advisors produced a different process that was effective on the upper level. Those of President Clinton produced one that was quite effective internally.

There are no set rules for advisors, but the golden rule seems essential. Another key attribute is the "plays well with others" we are supposed to learn in kindergarten. Unfortunately, scientists tend to fall instead into the category the British call "eminently un-clubbable," which is impressed on them by their competitive training and advancement. But science advice, like politics, is a consensus building, and one makes coalitions by addition, not division. Thus, it has often been the case that the most effective science advisors have been the best builders rather than the best scientists.

Summary and Conclusions

Service at the policy level in government is a privilege entrusted to few, and there are few positions to prepare one for it. However, there are some principles that are common with other professions, of which military command and control appears to be one. Both involve a structured process in which the principal must survey his environment, formulate the appropriate response, execute it, assess the results, and respond accordingly. For a science advisor, the process is complicated by the need to play simultaneously on two levels where the players have very different backgrounds and one has largely nonscientific agendas. However, the above discussion suggests there is significant overlap in the skills required.

Science advice came to the White House relatively late and has functioned with varying degrees of success. It seems to have been most effective in administrations in which both the president and the advisor had a common understanding of and experience with the command and control process—and the personal affinity needed to bridge the levels needed to affect it. It was less effective in administrations where the advisor or one level was absent or weakened. There have been large oscillations in the effectiveness of the process over time. They appear to have damped down in recent administrations, although the secular trend seems to have been towards operation at a lower level, with less impact, at a greater distance from the center.

Science advisors and their offices have played major roles over the last five decades. At times during the Eisenhower, Kennedy, Reagan, and other administrations, they properly put science at the center of national policy. In times of stress, science advisors and their offices played important and effective roles. Their roles tend to be diffused today by the growth in the number of players entering science decisions, the number of strong external players and pressure groups, and the centrifugal forces that tend to push science advice further from the seat of decision making. However, given the growing number of problems with strong science content pushing their way to the fore, it is unlikely that a return to the science night crew will be adequate, so it will be necessary to find a stable structure with an advisor strong enough to formulate the key problems and parameters, provide appropriate scientific inputs for decisions, and communicate the results to the scientific community and public.

NUCLEAR SECURITY PANEL

Raymond Juzaitis

When I saw the notes describing what the speakers would address, I noticed next to my name was the annotation: "nuclear weapons." Accordingly, I will speak generally about confidence in the nuclear stockpile as we enter the 21st century. (Anita Jones, I wanted to tell you that I am a very proud graduate of that nuclear engineering department in the University of Virginia, and when they closed down that reactor, as an alumnus, I was extremely disappointed. I am sure these are hard decisions, but for some of us they are hard to understand. Whether decisions are reached based on a serious strategic assessment or on politically correct accommodations.)

This morning I was listening to the talks and trying to pull my thoughts together on how I would segue from sustainable development to nuclear weapons. It is quite a bridge to make. There were some "footholds" provided for me by Ernie Moniz. However, what I would like to focus on is trying to weave a theme that relates things that we worry about on a daily basis in the nuclear weapons community to similar concerns of many here who work in different fields in the unclassified world of science and technology. There are some issues related to science that clearly do unite us, whether we engage in the classified or unclassified technical arenas.

What I would like to direct my attention to in these few minutes is the notion of "confidence." I am not going to talk about what kind of stockpile the United States should or should not have. I would like to address the very important issue of where the nation derives its confidence in the nuclear weapons that it does rely on to ensure ultimate national security.

Many of us have various notions of when the Cold War ended. Some of us see the Berlin Wall going down as signifying the end of the Cold War. Some of us noted the independence of the Baltic States, maybe that was the time the Cold War ended. Some of us noted the initiation of the Commonwealth of Independent States as the old Soviet Union disintegrated. Although there are many ways of describing it, for the nuclear weapons community, the end of the Cold War was the final week of September 1992, when the last U.S. nuclear test was conducted. It was a test called “Divider.” We named all our tests with creative names, but this one was literally quite prophetic, in the sense that it clearly distinguished the end of a very interesting era that characterized weapons development from the Manhattan Project days to 1992.

Ultimately, confidence in the nuclear stockpile throughout the Cold War was founded on nuclear testing. Even though a very significant amount of science in the form of theory, computations, and smaller-scale experiments contributed to the overall program, fully-integrated nuclear tests provided a unique “fly-wheel” for driving nuclear weapons technology, as well as integrating the multi-disciplinary efforts required to understand and develop the nuclear weapons. In some sense, rather than what are traditionally regarded as scientific experiments, they were really demonstrations—demonstrations that the design community could meet its technical objectives and demonstrate, first and foremost to themselves, that they knew how to wrangle with and exploit the physical processes that under-gird nuclear weapons performance. A nuclear test was also a demonstration to the policy community, and to the world, that the United States could indeed harness the power of the nucleus in effectively deterring any threat to its security from abroad.

So, the confidence derived from those tests basically spread throughout the whole nuclear weapons complex. It was on the basis of these tests that we established standards for the manufacturing processes that were used to fabricate the nuclear arsenal. These standards were found in the tolerances that were identified for the machining processes. They were found in surveillance procedures that were used to assess how the weapons were changing while they were deployed in that stockpile. This kind of confidence was completely satisfactory for the era in which it was relied upon. After all, aging was not a major consideration in nuclear weapons technology because we replaced nuclear weapon systems with high frequency throughout the first 40 to 50 years. In fact, the average age of the stockpile, up until 1965, was only five years for any particular weapon system. After 1965, which, interestingly, also signifies when the United States adopted Mutual Assured Destruction as a deterrence principle, was the peak of our build program. After that, the build program softened somewhat. The average age grew to about 15 years in the late 1980s. Clearly, after we retired some of the older systems in the early 1990s, the age dropped, but now, by 2005, the average stockpile age will be 20 years and will be growing year for year. So we are finally reaching a point where true aging is a consideration, and there will be no nuclear tests to aid in establishing empirically derived confidence in the aged nuclear weapons.

In 1992, when the last nuclear test was executed, we knew there was going to be a difficult change for the technical community. In 1993, when President Clinton extended the moratorium via executive order, he challenged the nuclear weapons community to vouch for the safety and ensure the reliability of the nuclear weapons stockpile with scientific means but not by employing any more nuclear tests. That basically signified the start of the Stockpile Stewardship Program, which was later further developed through the visionary work of Assistant Secretary of Energy (Defense Programs) Vic Reis, working very closely with the National Laboratory directors. At the core of Science-Based Stewardship is the employment of the discipline of science and scientific method to inductively establish confidence in the weapons.

Nuclear weapons issues are always challenging the technology-policy interface. Obviously, the decision to refrain from testing was one of these issues. We note that the commitment accepted by the United States in 1995 to adhere to the zero-yield provision of the Comprehensive Test Ban Treaty (CTBT) reflected one significant transfer of risk from the policy community to the technical community. Given that proliferation concerns were clearly paramount in considerations of whether to continue nuclear testing, the risk that was reduced in the proliferation arena was transferred to the technical arena. For a country like the United States that prides itself in technological infrastructure and capability, that may have been a good risk to take! If there is any field of endeavor that the United States clearly has as a competitive advantage, it is in its scientific and technological innovation and prowess.

The question is: Will this suffice to ensure confidence in the deterrent for the foreseeable future? It was a great technical challenge and now we have lived it for 11 years. It begs one to reflect on whether Science-Based Stewardship is still the right way to go for the nation. Clearly the program was built on the strength of the technical programs at the National Labs. As far as costs go, it was a fairly cheap risk transfer, because apart from DOD costs, the overall cost of the stewardship program to the nation over ten years was much less than $50 billion. One can compare this to the $87 billion that was targeted for Iraq reconstruction in 2003. Considering this was a decadal program that seems to be a pretty cheap price for the nation to pay for stockpile confidence while sending a strong message to the international community. Was there true lasting value in this effort, however?

Now it is time to reflect on those 11 years and see how confidence has evolved, how it has grown, and how it as dropped. We found that, to be successful, Stewardship could not simply base itself on the post-Cold War paradigm for funding science, instituted by Vannevar Bush (among others) in the late 1940s. Simply stated, this was a linear development model that based itself on funding basic scientific research and waiting for the natural forces of innovation to drive advancement in the more applied technical fields. In this model, you would pump a lot of money in basic science and out at the end of the pipeline would come confidence in the continued performance and reliability of the nuclear stockpile—someday. Unfortunately, this model would not work for the focused and time-urgent effort involved in nuclear weapons Stewardship.

So, Assistant Secretary Reis initiated an era of focused initiatives. To advance the timescale for making progress, we argued for various initiatives that could convince Congress that Science-Based Stewardship would make a significant difference in our approach to certifying stockpile reliability, performance, and safety. The Accelerated Strategic Computing Initiative (ASCI) was a major one, because everyone knew that, short of nuclear tests, simulation and computing was going to have to be a central piece of the technology puzzle. Some thought that it was the whole puzzle—we heard a lot of talk about "virtual testing" by simulation. But that was not the answer by itself. The initiative was important because, clearly, computation and simulation are essential components of Stewardship, but the puzzle was not complete without some more critical pieces. The multi-scale simulation models used to model nuclear weapon performance needed to be grounded in physical reality, needed experimental validation.

Accordingly, we saw investment in a lot of experimental facilities, such as laser facilities to provide access to high-energy density regimes, albeit at a very small scale, and thus The National Ignition Facility was born. Advanced Radiography machines were also considered essential for exploring the early hydrodynamic phases of the weapon's implosion system. All of these together, as initiatives, do not build back the confidence that is eroding slowly as we advance in time from the era of nuclear testing experience. What is really required, and what we are now focusing on, are not simply uncoordinated initiatives, not just the sprinkling of money to support sciences that are relevant to nuclear weapons work, but a directed, methodical integration of these capabilities into a science-based prediction regime. So, science-based prediction of weapons performance, which evolves from a very tightly directed integration of experiments, theory, and simulation, is what is going to be the integrating principle that will underlie stockpile confidence in the future.

For the nuclear weapons design community to demonstrate that there is a true predictive capability, it will be required to articulate where the greatest physics-based uncertainties exist and link these uncertainties to nuclear weapons performance, safety, and reliability. It is in understanding and linking these, and carefully managing and reducing uncertainties, that the ultimate challenge of Stewardship lies. Quantified uncertainties will be related to the performance margins that have been designed into the nuclear weapons when these weapons were tested underground. This will provide methodical rigor and discipline to the framework for the process of certification and will allow us to integrate all the work of these initiatives into a directed program of science-based prediction.

This is where I want to end, because I would like to propose that science-based prediction is also the umbrella that would cover a lot of the very difficult problems that we have talked about today—technical problems that challenge our nation's policy makers. Science-based prediction, which is a focus on quantifying fundamental uncertainties associated with our understanding of physical and chemical processes and concerted effort to reduce them, will also help to solve the global climate problem, will help to develop smart sensors and arrays of sensors for the Homeland Security program, and will also help develop vaccines to protect us from the unimaginable biological threats to our national security.

There are numerous fields of technical endeavor that highlight such challenges. The way to characterize the problems that are amenable to this kind of approach is enumerated as follows: First, they involve highly complex, dynamic systems that evolve in a very nonlinear way, such as the evolution in performance of a nuclear weapon, or the evolution of global climate. It will be critical to build a systematic understanding of the interaction of forces and processes, couched in the light of basic science, not empiricism. Second, the solution to these problems will rely heavily on computational technology and simulation science. Third, these will be multi-scale problems linking scales of nature from the nano- and micro-scale to the continuum scale, requiring predictive capability that will leverage knowledge on one scale to predict phenomena on higher scales. Finally, many of these problems will involve critical and very expensive choices to be made by our nation's policy-makers.

Science-based prediction will play a huge role at the policy-technology interface. If done right, the new paradigm could bring even more progress and prosperity to our nation than did the Vannevar Bush paradigm embodied by *Science: The Endless Frontier*. Our collective dedication to building a strong national and international prowess in science-based prediction will join all of us—across the seemingly unbridgeable classification divide or our work—in a common enterprise to benefit humanity.

NUCLEAR SECURITY PANEL

Discussion

Question: As you know, I greatly appreciate the analysis that has come out of MIT, but this whole issue of getting the nuclear future straight is one we have to begin to grasp and resolve. There are certainly questions about the borehole approach, as you know. The Yucca Mountains are very expensive and hard to come by. Go back one more time for me and reconsider this recycling, reprocessing possibility, and put it in a time frame that we can think about, both in terms of economics and technology. I agree that starting one or two years from now is pretty silly, but it also occurs to me that all things add up in such a way that without a closed-fuel cycle, we will never even come close to taking full advantage of this energy possibility.

Moniz: First of all, we do have to always remember the length of time it takes to introduce new technologies. In the nuclear field, for example, it has taken roughly 30 to 40 years to learn how to operate the reactors that we currently operate. In fact, the time frame to do so has led to significant policy problems in many ways. Then there is always the white elephant problem.

Now the context would be the path we laid out. If nuclear power is to be a reliable option, and that is a big if, of course the code power plants, which are the only option for several decades, must work well, safely, and there must be some built to demonstrate that, in fact, the economic challenge is very substantial. Certainly for a country like the United States—and I am assuming that, one way or another, we are not talking the old vertical monopoly where you could afford to cover the costs substantially—the economics are very challenging, just for building the technology we have already been building for thirty years. To start thinking about adding to that a complex fuel cycle that is going to add tremendous costs, tremendous complexity, just does not make sense for a while.

So, I think we have to get through that. If we want to go to a recycling fuel cycle in the intermediate term, we can do that. It is being done right now in France, after all. The MOX fuel cycle, in my view, has no redeeming social features of benefit. It costs more. We have had long talks with the French on the costs. We agree on the sign. We disagree on the magnitude by a factor of two. But it is true that in overall fuel cycle cost, whether it is a factor of two or four, we are talking about 10 percent on total fuel cycle costs to be fair.

However, the emphasis on what I stated was that what we do not want is the MOX fuel cycle to be viewed as a good promotional pathway for the spread of nuclear power. I will accept the fact that the French know how to protect their stuff. However, all of you, including Los Alamos, what you are talking about in the future is a closed-fuel cycle that is not the MOX fuel cycle. In fact, it will probably have very little overlap with the MOX fuel cycle. It will probably have a fast reactor rather than a thermal reactor. Every fast reactor built has been a dog. You have got a cost-reduction issue, if nothing else, on a fast reactor of immense scales. Alone, we are talking decades before possibly resolving that problem.

You were talking about a preprocessing plant. The MOX system has a reprocessing plant, but it is probably going to be a very different preprocessing plant. It is a whole different technology, which means a whole different fuel fabrication infrastructure. So, why go to that point through this proliferation of an unattractive feature? Why do not we work together—the DOE labs, the American universities, the French, the Japanese, the Russians—and really go back to the basics, getting a strong analysis simulation approach to start, understanding the science and engineering data we do not have, and start doing? We are talking about real lab work to move forward. This is a multi-decadal effort.

Jumping the gun with big demonstration plans is probably another excellent way to come back to thirty more years of nothing happening. All I have to say is do this right. There are various views about how this would turn out. I personally have a hard time understanding how the economics of this fuel cycle are ever going to come out and be dependable, but I am very happy to be proved wrong, because fifty years from now, or a hundred years from now, if nuclear is still an important option, there may be higher fuel-cost problems, the economics may be better, and it may be a long-term approach for waste management.

The way I see it is, if we could move to this kind of institutional and technical structure for advanced fuel cycles for an expanded power future, and we have this idea that spent fuel is being moved to a relatively small number of countries who must be comfortable with their waste management decision, I have no objections if the Russians want to take it and reprocess it. Who knows, maybe we want to take it or the Canadians want to take it and put it in a deep borehole. But you make that choice. If you want to pay extra money to reprocess it in Russia, fine. But get the fuel cycle right, which is going to take decades. Do not fool yourself. Technologies that are far from implementation look very cheap. Well this one does not even look cheap now.

Question: The point about the demise of UVA's nuclear engineering, has there been an analysis to suggest how widespread this is? Is it at a critical juncture?

Moniz: It is widespread. A significant fraction of the research reactors have been shut down. Michigan is shutting down theirs. I would just add something to make it a little direr. At MIT, the engineering department dodged the bullet in terms of existence. It exists. However, and I am not saying this is bad or good, but as a statement of fact, I would say that their portfolio of activities do not resemble what I would call a lot of hardcore fission reactor engineering. They do a lot of health and much broader studies.

Question: Is it perhaps time to think about a strategy that is similar to what we did in response to Sputnik? There, the federal government funded dozens of new departments, and they fully funded faculties and research. Is it time to consider something like this, even though there may not be jobs guaranteed? We would train students. They would go to work in France and China and Iran for a while, and when we are ready, we will bring them back.

Jones: I think if you want to get first-rate students and first-rate faculty, there has to be a clear and attractive path whereby they can use that education. The lack of jobs in the United States will be a detriment to students and faculty working in the field, even when there are jobs in other countries for experts in nuclear power generation.

Moniz: I just want to add that your statement is very subversive. Sending these students out to other countries would be returning them to their countries of origin.

Attendee: I think you need to understand the size of the problem you are talking about. In 2001, there were one hundred nuclear engineers produced in the entire United States at the bachelor's level, and 82 Ph.D.s, over thirty of whom are born nationals.

Question: Los Alamos does some nanotechnology work, biotechnology, computer science, and lots of fundamental theory in physics and chemistry and biology. What is the point from your perspective? How is it that that makes sense, given the important missions of the laboratory?

Juzaitis: I think it has always been the perception that a key part of the national laboratory is to make sure it has a portal to the best and the brightest in science and technology, which would allow for the recruitment of talent for the nuclear weapons program. From a nuclear weapons perspective, from somebody who cares about having the best and the brightest working on our nuclear weapons program, that is really the pipeline that the nuclear weapons program has to work with. I think that is why, for a national laboratory, it is critical that these two worlds do work together. I know funding and mission pressures sometimes bring that issue up (but Meyer may have a different perspective) but you heard about two sides of Los Alamos. Meyer talked about the strategic research part, and I talked about weapons physics. I think the interfaces between those parts of the laboratory are very healthy and are, in fact, critical for the success of the Stewardship program. The National Ignition Facility being sited at Livermore—part of that strategy was clearly to give Livermore that portal to the open science world.

Attendee: A lot of the success of just what you described is due to a strong partnership relationship between yourself and your colleagues at Los Alamos. It has not always been the case at every stage through the history of the laboratory. But that kind of cooperation and mutual support, and mutual understanding in the laboratory, just seems to me key to be there in a continuous basis.

Juzaitis: The one thing that hurts that goal is squabbling between the Department of Energy's Office of Science and the National Nuclear Security Administration (NNSA). That can take away all the benefit of the positive indicators that I talked about before.

Moniz: Clearly, the integration of all these activities and disciplines at Los Alamos are important for recruiting and for vitality. However, since you mentioned the DOE's Office of Science issue, I think it is also important that the NNSA, which has taken some steps, should take much more aggressive steps to see to it that there is a lot more work being done also in the universities, particularly along the line of developing the kinds of intellectual structures that you need in the program. But you know it is really hard for the DOE's Office of Science to move out in the universities on a scale that would ultimately help you much more. You guys, as you well know, needed a huge amount of help on algorithmic structures, which you cannot get from the universities. This is not criticism by any means, but I am saying that the bridge between those stovepipes needs to get much better.

SCIENCE AND TECHNOLOGY POLICY

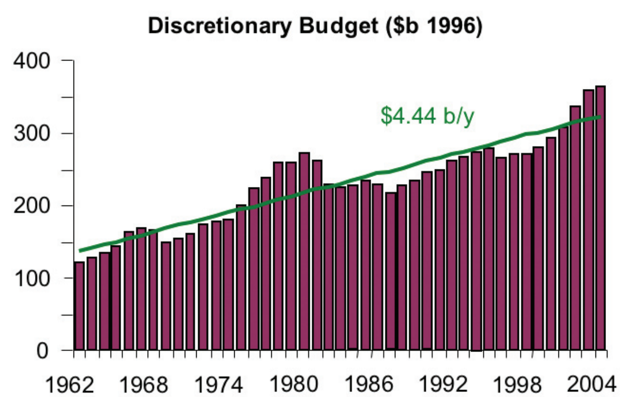
SCIENCE POLICY FOR THE 21ST CENTURY

John Marburger, III

I do not intend to give an overview of my role or office as many of my predecessors have done so eloquently in publications, such as William Golden's useful book *Science and Technology Advice to the President, Congress, and Judiciary*, where he addresses a symposium at MIT on the occasion of the OSTP's 25th anniversary in 2001. I am going to talk about three topics somewhat connected at the center of our national science enterprise: funding, priorities, and implementation. Let me talk about funding first.

When physicists try to understand a natural phenomenon, they look for invariants and symmetries. Few would describe the federal budget process as natural, but it does exhibit some interesting invariants in the data. That is where I would like to begin today. Funding for science is obviously an important bottom line in science policy, and money is a medium that energizes the whole enterprise. For science, the interesting part of the federal budget is the domestic discretionary budget. The Office of Management and Budget (OMB) publishes figures for this that extend back to 1962 in constant dollars. The domestic discretionary budget defines the arena in which all complex forces are brought to bear that drive the nation's research and development budget. Here is the magnitude of that budget in constant 1996 dollars for the past four decades (Figure 1).

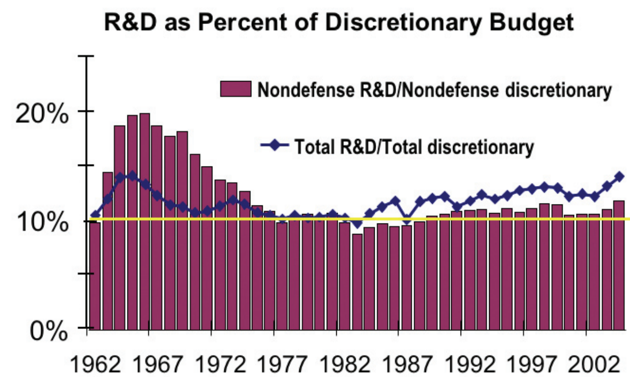
Figure 1



Except for fluctuations that have approximately the scale of the sun spot cycle, this discretionary budget in constant dollars is more or less linear. The curve is reproduced rather well by its least-squares, straight-line estimator whose slope is about $4.44 billion/year in 1996 dollars. This is the amount of new money that is injected into the pot each year.

It is a convolution of the growing economy and the governmental budget process, which is rather complicated. In 2003, this pot is ahead of the curve. What share of the pot has science won during these four decades? There is the fraction of the domestic discretionary budget devoted to non-defense R&D for four decades (Figure 2).

Figure 2



The bulge at the left in Figure 2 is due entirely to the Apollo program. If you remove this bulge, if you remove the Apollo program, the U.S. R&D budget has been approximately 10 percent of the domestic discretionary budget for four decades. So putting these two pictures together, we find that on average, year in and year out for the past 42 years, the United States has added nearly one half billion 1996 dollars to the non-defense R&D budget every year. Once again, during the current administration, the expenditures are ahead of the curve. I have no explanation for this persistent feature of the federal non-defense R&D funding. Nobody particularly tries to achieve 10 percent of the discretionary budget, but it appears to be very robust. It signifies the sort of balance and equilibrium among the diverse forces that contend for the domestic discretionary pie. Recall that the contenders include international affairs, transportation, education, housing assistance, veterans benefits, and many others. Even a small fluctuation in a $400 billion pot is significant for science, but I want to emphasize that the funds available for science are by no means chaotic or unpredictable and I do not expect this situation to change. The rate of growth is relatively steady on the decadal time scale of big science projects and even longer time scales that characterize the rise of entirely new fields, such as molecular biology. There is no evidence, except for the data itself, for anything like Boltzmann's H theorem—for those physicists in the crowd—that requires fluctuations from trends to relax back to the 10 percent share with linear growth in the domestic discretionary budget, but the lesson of the Apollo program is intriguing. Permanent increases above this natural growth rate appear to be unsustainable.

The natural growth rate is a respectable number and we ought to be able to do something with it if we plan and prioritize. Given this situation, which is relatively stable if you believe history, you have a limited number of things you can do within it. The pot is growing, but you have to be careful about what you spend the money on because there is not an infinite amount of it. All science advisors have to be obsessed about planning and prioritizing in the chaos of budget making. There are two driving forces for coherence in the federal budget. One of them is the president's budget request itself. It is not entirely coherent, but we try to make it coherent. The other is the inherent structure and status of science. I take it as one of the responsibilities of the science advisor to align the president's budget with the opportunities that science naturally presents in the course of its development and evolution. There are other large forces, which are not particularly coherent, including the needs of society in different eras and the shorter rhythms of political styles and processes, including changing administrations.

The intrinsic organizing power of science itself, I believe, deserves more attention than it gets in discussions of science policy. In my frequent visits to universities, national laboratories, and conferences, I am always impressed with the efficiency of communication between working scientists. They know what they are doing; they read each other's papers and keep up. There is a very high degree of coherence that emerges from the science and technology, where leads are identified, publicized, followed up, and trends emerge spontaneously in widely separated places throughout the world. Good ideas are not ignored for long. Despite all the criticisms of peer review for programs, grants, and publications, it does work.

The market mechanisms of science in America are exceptionally efficient. What this means is that there is wide-spread agreement among scientists about the status and opportunities that exist in science. There is a remarkable degree of consistency in pure assessments and advisory recommendations worldwide. When I talk to my counterparts in other countries, they are very interested in knowing what we are doing. I am interested in knowing what they are doing. When we compare notes it turns out to be pretty much the same thing not because they are copying from us, but because they are listening to the science community, which has this extraordinary built-in coherence. We owe a deep debt of gratitude to the many organizations, from the National Academies to the multi-branched organizations and professional societies, which make this machinery work. I am aware that this very consistency leads some critics to suspect a vast conspiracy of establishment science that somehow imposes its will. Well, there are some artificialities in the consensus, but I think most of it accurately reflects the real state of affairs in science.

This consensus about opportunities in science is not enough. Science has an insatiable appetite for resources and at some point choices have to be made. Fifteen years ago in his address to the 125th annual meeting of the National Academy of Science, Frank Press launched a brave and highly visible effort to enlist the science community in this prioritization process and was roundly taken to task at the time by his colleagues before succeeding. Some of you probably remember the media when Frank gave his speech. Recent science advisors, including Neal Lane and myself, have tried to learn from Frank Press' lesson. We have taken different approaches, more subtle and less visible. You may remember that Frank identified three categories with names of programs in each priority level. Congress got upset, because they thought that they should be doing that, and the science community wanted no part of prioritizing among each others field. They could identify what was important in their field, but they did not want to participate in selecting among other fields. Some of the criticism occurred because of the criteria for the categories allowed for too much judgment in the sorting out. The more usual path is to try to make the criteria as self-evident as possible and rely on a smaller, less public process to make the final hard decisions. Unfortunately, it is very difficult to make comparisons across fields, which is ultimately what needs to be done.

In my opinion, a very important contribution to cross-field prioritization, which was by no means uncontroversial, was Alvin Weinberg's July 1961 article in *Science Magazine*, called the "Impact of Large-Scale Science on the United States." It was a very important article. Some aspects of the article where incorporated in the book that Weinberg published about six years later called *Reflections on Big Science*, but the paper itself is much more pointed and it asks questions in a very critical way that are relevant today. Here are the questions that Weinberg asked:

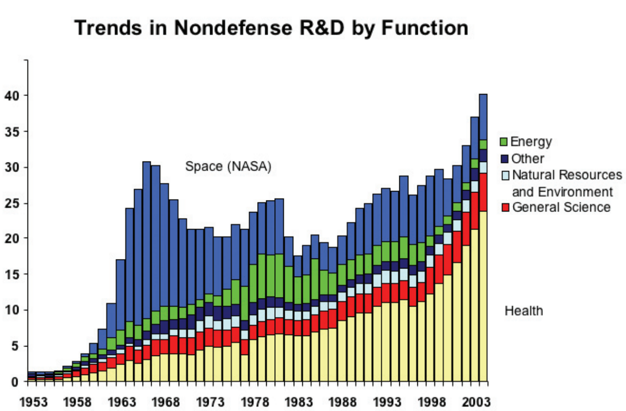
1. "Is Big Science ruining science?" Weinberg thought so, but I do not.
2. "Is Big Science ruining us financially?" Well, we have not gone broke yet.
3. "Should we divert a larger part of our effort to scientific issues that bear more

> directly on human well-being than do such Big-Science spectaculars as manned space travel and high-energy physics?" You can hear Alvin stacking the deck with these words.

Recall that President Kennedy had given his historic speech launching the Apollo program earlier that year, and NASA's budget was increasing at a rate that would soon put it way over the 10 percent trend line that we have identified for non-defense science's share of the domestic budget. Other areas have grown, but only the growth of medical research has been steady, culminating in the recent doubling of the NIH budget. Weinberg asked his questions about big science at a time when the sciences' impact "more directly on human beings" was still small. During the intervening decades, small science has grown up. This is more than just health research. The evolution of computing and instrumentation during the past four decades has accumulated to a revolution that is transforming all science. It opened attractive opportunities on what I like to call "the frontier of complexity," which includes life sciences as well as many other areas of science.

While all this change was taking place in the instrumental and information content of science, the Cold War was grinding its way to a conclusion in the early 1990s and Congress began to reassess the rationale for federal support for all the sciences, particularly for the physical sciences. In Figure 3, the only visible evidence of the end of the Cold War is the acceleration of funding for the health sciences relative to the other fields. Part of the reason for this was the lingering conviction within Congress that the basis for supporting physical science and its origins was in national defense.

Figure 3



During the early 1990s, in the aftermath of the collapse of the Soviet Union, funding for research for both the Departments of Defense and Energy began to stagnate, while funding for the NSF and particularly for NIH advanced. During the technology boom of the 1990s and towards the end of the century, economic analyses began to appear that showed how closely related the advance of important new technologies was to prior investments in science and basic research, particularly in the physical sciences.

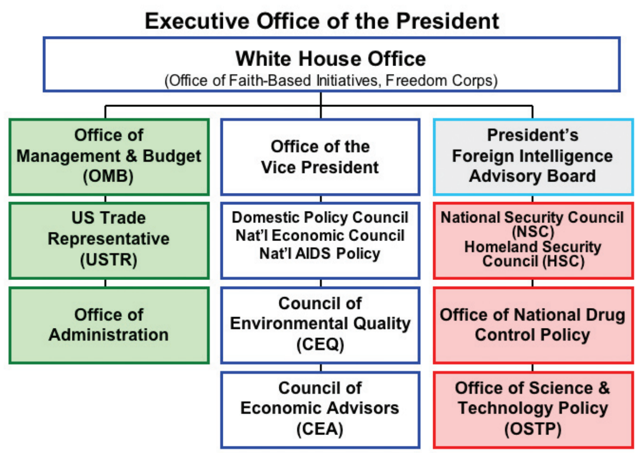
The growing demand by biomedical research for access to instrumentation added to an increasing concern that physical science funding needed to be accelerated. Harold Varmus, then director of NIH, emphasized the reliance of biomedical research on underlying physical science and said, "A national commitment to train and support the best minds in these varied disciplines can improve the health of people here and throughout the world." It seems to me that the post-Cold War uncertainties about the basis for physical science funding have largely sorted themselves out. The DOE has done a good job of realigning its national laboratories and providing good rationales for their missions. Ernie Moniz, who is in the audience today, drove this process while he was there with a department-wide, road-mapping effort, which is badly needed in some other agencies that have missions other than science. It is an important effort; we have come a long way, since those years immediately after the Cold War ended, in understanding why we support the various areas of science.

The priorities of this administration, of President George W. Bush, reinforced the realignment between the physical and life sciences with specific initiatives. Some have their roots in earlier policy movements and were built on previous policy priorities as well as some new ones, but it is pretty clear what we have to do. The remarkable, inexorable convergence of nanotechnology, information technology, and biotechnology is a major driver for these priorities. Emerging concerns about terrorism have also significantly affected this concern for technology, but in general, despite the preoccupation with the technology and the systems required to protect our nation against terrorism, the overall trend of science is that the inherent opportunities are working themselves out. They are making themselves manifest and are relatively immune to the shorter trends of societal preoccupations. In the immediate future, like this year or next year, budget difficulties are going to make it hard to change the pattern of support very much, but there are priorities, and this administration is determined to make these priorities apparent.

Next. let me talk a little bit about implementation. We have a number of people here today, including many of my predecessors, who have grappled with this question of how to organize the OSTP and the other machinery of this nation's policy apparatus to make sure that there is coherence and prioritization in the planning of the president's request to Congress and also that Congress itself has incentives to continue to carry forward the coherent pattern of science and technology support.

The impressive constancy of science's share of the domestic discretionary budget is the result of forces that are by no means themselves constant or guaranteed. The share comes from a continued effort by a large number of constituencies and actors from the budget process. In each administration, this office reorganizes and reinvents itself to suit the demands of the time. Figure 4 shows what the White House looks like these days.

Figure 4



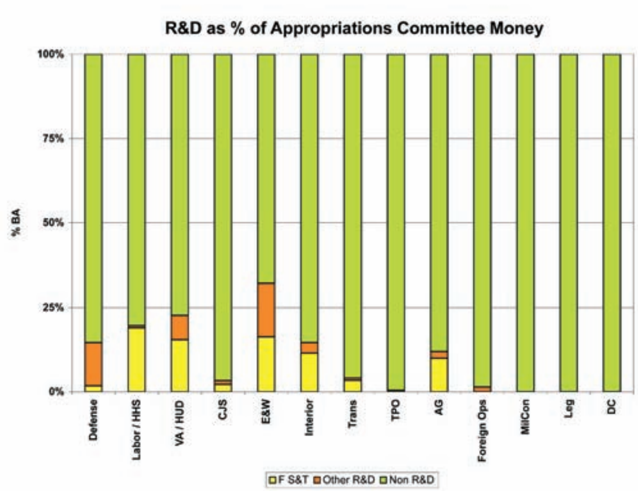
The White House environment has changed considerably because of the presence of the Homeland Security Council, which is now operating in parallel to the National Security Council. As far as I can tell, the balance of effort in my office that was tilted quite strongly towards the National Security Council has been replaced by an emphasis on homeland security for the past two years. We are now beginning to balance that and work more closely with the National Security Council to pick up some lost ground that we need to recover (there are some important issues that need attention), but there is no question that homeland security has received a very high proportion of OSTP's energies over the past two years and that makes sense to me. So, the Homeland Security Council operates in parallel to the National Security Council; it is modeled on the NSC model, and I have organized our office, OSTP, to give priority of our service to the Homeland Security Council and to the new Department of Homeland Security. The National Academies, under the leadership of their presidents, put together a report in a timely fashion giving many recommendations about what needed to be done to capture the science and technology energies of the nation in support of the homeland security mission. So today, OSTP has unusually close working relationships with OMB, HSC, and the National Economic Council, but we also work well with the other White House efforts.

I guess people have remarked on the tightness of the Bush team; the fact is that we do get along quite well. We talk, we communicate well with each other, and we try to work out differences before we get the President involved and present him with clear alternatives. I know every administration tries to do that, but there is a very high degree of interaction within this White House. It is very interesting to me, a very interesting dynamic, much tighter than I would have expected coming in from a university environment. Neal Lane has mentioned that the pace is faster in Washington than it is in universities, but universities have a certain excitement of their own that makes up for that, I suppose.

I regard the relationship with the OMB and Congress as particularly important, not only for insuring a rational science budget, but also for putting teeth in the entire inter-agency planning and prioritization process. We need to have attention from the agencies in order to get our work done, and I must say that the agencies do not always mind. They have to perceive that the policy apparatus is helping them achieve their ends, not just another interfering actor in the chaos of the budget process. So we have organized ourselves to increase our interactions systematically with Congress.

There is another interesting figure (Figure 5) that someone in my office put together that shows the percentage of each appropriation committee's work devoted to science.

Figure 5

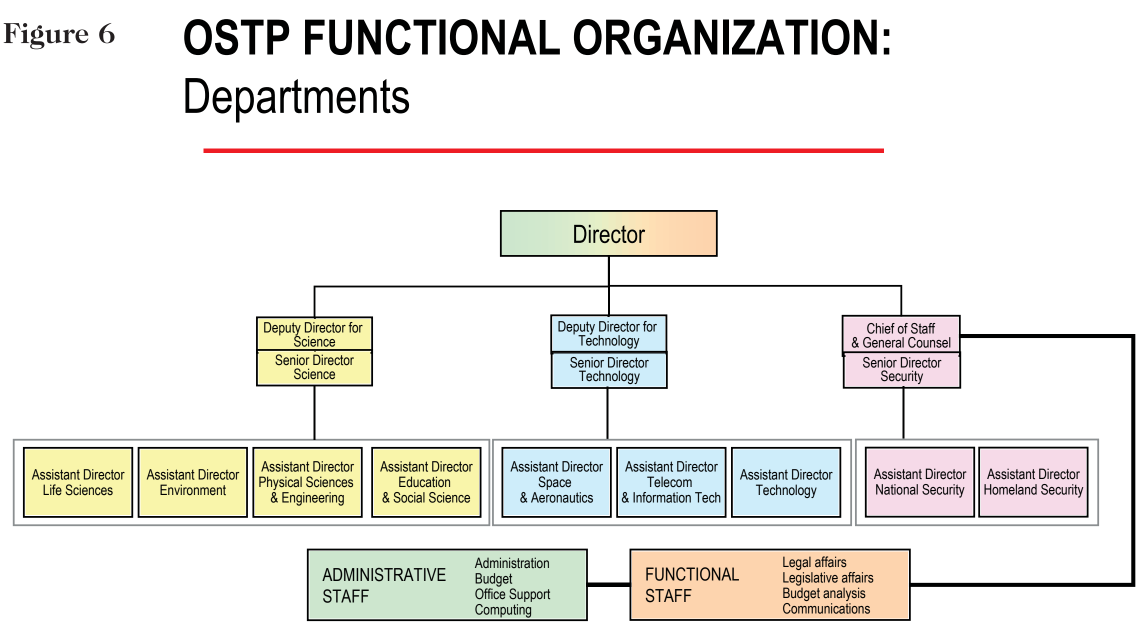


There are 13 appropriation committees in Congress, and some of them do not have any science at all in their missions, but some of them do. You can see that the nation's science budget is distributed among about ten appropriation committees, in none of which, even in the one that deals with NIH, has science as a major player. We have to contend with that; we have to give science the necessary visibility in each one of these committees in order to get a clear budget through the process.

I might add that the Department of Health and Human Services appropriation committee is the only committee that owns one entire field of science. If you look at physical science, for example, it is shared among four or five appropriation committees. The same thing is true for environmental science and even energy research; they are shared among different appropriation committees so that a program that looks very coherent in the president's budget, or in some abstract planning process, can easily be picked apart in the appropriation process so that it does not add up. These are inherent problems in the structure of the budget process that I believe is the responsibly of OSTP to address.

To that end, I have to organize the office so that it increases its engagement with Congress. We increased the number of staffers who have experience with congressional science committees. We also increased time on my calendar, so I can interact with Congress as well as with the agencies, and I have worked to get the office to work more as a team. Figure 6 is a functional organization chart of what OSTP looks like today.

Figure 6



I have a directorate, which includes my chief of staff and two deputies (two associate directors, who are Senate confirmed) and a support layer, which provides support to everybody. We try to work as a team on issues. That is to say, I meet frequently with my senior colleagues and we decide what direction to go in to divide up the activities and get the support staff to work with everybody. We tried to eliminate stovepipe completely, and the technical tasks are matrixed among these different departments. We also tried to strengthen the nine departments that cover the spectrum of science and technology areas and they truly work together.

There has been a lot of concern about the impact of moving OSTP out of the old Executive Office Building, where it was in close proximity to many of its customers. It was not a good thing to lose that immediate contact with other people in that building. On the other hand, we moved into space that is much more suitable for working together as a team. The effectiveness of interdisciplinary work and functioning together as teams on issues that emerge on a day-to-day basis has been vastly increased by the new space. The feel of the office has changed very substantially. I cannot say whether it is better or worse, but it is certainly well suited for the kinds of things that we are trying to do now.

Let me finish off with some remarks. We do need more coherence in how Congress addresses its responsibly for science. There are some important movements in Congress today, the current chairman of the House Science Committee, Congressman Sherwood Boehlert (R-NY), has been very helpful in this regard, and I want to acknowledge his leadership in trying to provide more a systematic approach to the science budget. Of course, there are strong supporters in Senate as well. Overall, there is strong bipartisan support for science in Congress; they want to do the right thing. The administration strongly supports science and I believe that the administration is attempting to use science in an appropriate way. We get a lot of respect, people return our phone calls, they ask us questions, and we can see evidence of our advice showing up in the proposals.

Many colleagues have asked me if OSTP is getting the support access and influence that it needs to do its important work, and I can assure you that it does, and that this administration respects and values the science and engineering enterprise no less than previous ones. That support reflects the effectiveness of all my predecessors and the high quality of the technical communities within the United States. I am deeply grateful to you and your support, and particularly to Neal Lane, who left a legacy of pride and accomplishment in our office for us to build upon. Thanks for letting me give these remarks this morning.

SCIENCE POLICY FOR THE 21ST CENTURY

Discussion

Question: Looking at the graph on the trends in non-defense R&D (Figure 4), the funding was very interesting. Can you comment on the returns that the nation has enjoyed due to those investments, and whether our investment strategy is in line with what we know about those returns?

Marburger: The returns on the investment are well-documented by a number of reports from the economics community in the past ten years. These reports indicated that most, if not all, of the productivity gains in the years of the bubble can be attributed to investments in basic research that took place up to decades before. Is our current pattern of investment consistent with what we know about that? No, there is an imbalance in the pattern of investments between the health sciences and the physical sciences. That does not mean that we have put too much into the health sciences, because there are extraordinary opportunities there, but it does mean that we have work to do.

This uncertainty and confusion about why we were supporting physical science that emerged towards the end of the collapse of the Soviet Union had a very negative effect on the balance and support for the physical sciences. Many of you lived through this. There was deep questioning. I remember talks by George Brown (D-CA), for example, who was chairman of the House Science Committee, warning us that the bottom was going to drop out of funding for physical sciences. The Galvin Task Force looked at the roles of the national laboratories and made some rather disparaging comments. I mentioned earlier Ernie Moniz's work. The fact is the agencies came forward with responses that tended to shift things toward building confidence that we knew what we were doing. Today, the Galvin reports, for example, are obsolete; they do not apply anymore to the DOE.

Things are happening in the DOD as well, and I think more needs to happen along these lines. There is a great deal of soul-searching and realigning within the DOD, which was another agency that had important investments in physical science that flattened out and deteriorated during these immediate post-Cold War years. Now everybody under-stands that it has to change.

There are new priorities that we have established through the budget process. We do not say physical science gets doubled, but we do say that there are important areas, like nanotechnology and information sciences, which clearly have major physical science components that we are trying to bolster. If you look at the pattern, not the actual amounts of money that go into the President's budget, you see that those priorities are reflected. So it is going to take time. After all, we have a steady funding pattern built in: it is 10 percent. And the linear rise in the domestic discretionary budget means that, yes, inevitably there will be more money put in every year into the science support. We have to use that as it comes in to build a pattern. But already the geometric expansion in the NIH budget has flattened and we are beginning to see the balance occur.

Question: I would like to touch on something that I call the visa crisis and our recent inability to even get the leaders of the Russian Academy and the Chinese Academy into this country. We seem to be disparaging our friends by subjecting them to quite unreasonable screening procedures over and over again. What we can do about this?

Marburger: The visa issues are very serious. We understand that we have to keep improving the process. I am very concerned about the impact of the delays in getting visas. We have to keep the pressure on and try to improve these processes so we can once again be open to important exchanges of ideas. Let me break the problem into two parts: student visas and scientist visas. The student visa problem is being fixed. The Student Exchange and Visitor Information Service (SEVIS) system for registering foreign students did not create as much of a problem as we thought it would this summer. It worked better this summer than it did the previous year.

The Department of Homeland Security, which now has responsibility to make this work efficiently, has really been quite positive about investing additional dollars and helping solve the student process. For example, students now have multiple-returns visas, so that you get it once, it is good for a year, and you can have unrestricted travel without reapplying. Unfortunately, the category of visas for scientists who are visiting for special programs and conferences still needs a lot more work. It would be important for us to try to find a way of characterizing the negative impacts of the current situation on the science and engineering enterprises, private commercial and industrial as well as academic, so that we can make the case as strong as possible. We are working on this every day in our office, but constructive suggestions from the science community are very welcome.

The American people demand that the federal government take all reasonable actions to protect them from terrorists. Within the State Department, the Department of Homeland Security, and the Justice Department, no one wants to be the person responsible for letting in the next terrorist who causes an attack, takes lives, and destroys property. So, we have a great concern to do this right, but we also have to do it in such a way as to preserve our science leadership. These are words that I say frequently, but behind the scenes we are working literally every day on this issue. It is something that has taken a lot of energy from us.

Question: You highlighted very large increases in the budget that were closely aligned with missions or objectives that the nation set out: manned space, the Carter administration's alternative energy use, and national security. It strikes me that the government has organized around those kinds of missions (the Department of Energy focuses on energy and the environment, NASA focuses on space, and the Department of Health and Human Services focuses on health). A tie that is not there, and is not present in the organizations and the agencies, is the tie between basic engineering and science research and the economic future. There is not a strong tie between Treasury and this community, and it seems to me that coming into the future, that might be a major motivation for setting our priorities and for perhaps making increases in places that would otherwise not be popular. Can you comment on that?

Marburger: Most of the explicit priorities that occur in the budget proposals from this administration are tied to applied areas. There is widespread agreement that it is the role of the federal government to fund high-risk, long-term basic research and it is the role of the private sector to fund short-term, lower-risk research. Nevertheless, most of the specific programs are somewhat targeted: the National Nanotechnology Initiative (NNI) is one. That has a basic component, but it is also understood that investments in this area are very likely to lead to innovations associated with economic competitiveness. In this country the link between federal investments and economic policy is deliberately weak, and although it fluctuates from one administration to another (Democrats and Republicans have slightly different views about this), it has not been U.S. policy to have an economic policy link with research. That link is embedded in the distributive nature of the funding in the agencies; multiple missionary agencies have a spectrum of basic applied research. This is one of the fascinating topics that I think this conference was organized to think about.

Question: One research agency that has really played a critical role in our national innovation system is the Defense Advanced Research Projects Agency (DARPA). Although they have enjoyed very significant budget increases under the Bush administration, there has been a shift toward supporting defense contractors and much more of an emphasis on 18-month deliverables. In terms of engaging the university research community, which is generally organized around the length of getting a dissertation, that's pretty disruptive. I am wondering if you have heard these concerns from other people within the university research community and whether you think there is anything that needs to be fixed here.

Marburger: Let me be straightforward about this—I do think the DOD needs to be investing more of its research and development dollars in the basic areas 61 and 62 to research. I think the current levels are too low; there is a problem that needs to be fixed somehow. That is one of the things that we are looking at. There is an acknowledgment of the top leadership in the DOD that basic research is important, but I think the DOD has not done as good of a job as the DOE has in reorganizing its old research structure in the post-Cold War era, and that is beginning to happen. There are movements within that are beginning do this, but there is more ground has to be covered.

Question: In a world of science ministers you are, in effect, the U.S. science minister. Could you comment on how you perceive your international role and the role of the OSTP?

Marburger: The OSTP has traditionally played an important role in bilateral conferences and in forming international policy. We continue to be an actor there, and as you know, the creation of the office of science advisor to the secretary of state has been a very important step forward in making our relationships with the State Department more effective. Not only has this office been created, but one of the things that this audience should know is that Norman Neureiter, as the first occupant of that office, has put into place a series of movements to get more science fellows and interns into the State Department and that has helped a lot. There is no question that science is an international phenomenon and that the United States has a tremendous interest in participating in science and engineering on an international basis. I mentioned that small science has grown up, so now most areas of science that are really important to us are big science.

We can gain greatly by investing in some of this big science in collaboration with other nations. The President made the decision to rejoin ITER. We are collaborating in a very important way in space science, and I believe that we can do this in other dimensions as well. We certainly should be collaborating for development of huge instruments for basic science. I think that, in general, we would tend to collaborate less on instrumentation that's important for economic competitiveness. There is no reason for us to invest in X-ray light sources, for example, in Europe. We need to be supporting our own X-ray light sources, which are useful for a very broad range of applications of importance to the economy. So I think that our national guidelines for collaboration opportunities with other countries also go back to the visa issue. We have been the primary beneficiary of immigration patterns and technical talent from around the world for more than 50 years, and we cannot close the door to those opportunities in the future.

SCIENCE AND TECHNOLOGY POLICY: ADVICE IN GOVERNMENT PANEL

H. Guyford Stever

This program deals with the gap between society and science. I worry quite a bit about that, because science is part of society. There are lots of gaps, but they have their unique characteristics. Since I am quite a bit older than the other people who are involved in this, I sought out a gap between science and society that would really illustrate how long and how powerful this gap has been. Copernicus told us that the Earth was no longer the center of the universe. That was a big gap. Immediately science advice came in. The Pope had his advisors and he refused to accept this, and Galileo was caught in the midst of all this. Most of his life was ruined by his punishments. He even had to recant a little bit on this.

I am just trying to show that there always were gaps between science and society with big blockbusters such as evolution. We cannot stop this process that science gets new capability, new knowledge, development, applications, and then we have to handle it somehow. All the time, there is a group of people in society who are quite worried; they are worried about the loss of identity.

Society recognizes that science is probably the most creative process, but it also is deeply concerned because some of the results of this are very serious. On this subject, Harold Shapiro gave a wonderful talk at a meeting in Lyon, France. He spoke about meaning in people's lives and what scientists' attitudes should be. I am going to steal from him four points that he suggested scientists should carefully look at when they come out with something new and shocking. He said that, "Perhaps the principal lessons of all this are the following: a) the expressed anxieties we hear about are real and we need not only to educate others about the potential of science alone in dealing with certain important issues. b) We should not confuse what we can do with what we should do. c) The special public policy challenge in liberal societies may be summarized by the following questions: Who decides, and for whom, and on what issues may the government act? d) The world of science and the world of meaning are so closely connected that realizing the potential of one requires dealing with the other." I think that is a very learned suggestion.

Now, this gap works both ways. Most of time you think of the gap of which the people who are not scientists are concerned, and those who are scientists are not concerned. When Sputnik hit, it was exactly the opposite. The population was scared stiff. We were in the midst of the Cold War. We were frightened in every sense. This pressure from the people being frightened forced the government to act, and that was in fact when the science advisor's office got started. President Eisenhower brought James Killian, Jr. into his position in the White House, which brought a great deal of relief. I talked with Marburger this morning and I gave him a piece of advice: "Do not to take the advice of any previous science advisor." Marburger has done a fantastic job, and to the speakers later on this program you have got a tough act to follow. Yesterday, after John Holdren gave his all-encompassing report on one major problem in society, I told him that he had given a tough act for the following speakers.

I would like to point out the shock in my life when the science advisors' mechanism was destroyed, kicked out of the White House by President Nixon and along with the President's Science Advisory Committee (PSAC). I could never forget the day when, as head of the National Science Foundation (NSF), I went over to the old Executive Office Building where PSAC was meeting. The heads of the department used to come and have some exchange with them at the end of their meeting. Luis Alvarez burst out of the meeting and said, "We've been fired! We've been fired!" Just like that. Shortly thereafter, I learned that all the OSTP's jobs were going to be given to the NSF. I had more than mixed feelings. I did not really want to do it, because I felt it was wrong, but some of my friends said that if I did not do it, someone else would. They can always find somebody. I was given about a weekend to tell the White House, George Schultz and Roy Ash in the OMB, what we should do. I asked if I could consult with some of the members of the National Science Board (NSB) and they said, "No. No, we don't want them in this at all." Fortunately I was able to get them back in.

The speech yesterday where John Holdren talked about the problems of energy in the environment, I always think of this as e^3—energy, environment, and the economy. Holdren was talking right along the lines that we started with. That was the time I was asking myself, "What should we start with?" The first thing we did was review the work that PCAST had done on energy in the environment. They had a very good report out on the subject, and we began to try to get it into action. We prevented the Atomic Energy Commission from capturing all the new money that would be put into research. We did that by getting some of the most powerful people in the country together and giving the OMB programs that were not in atomic energy, and we went on from there.

One last thing, because this is international, my office at the NSF was flooded immediately by the science ministers and the science policy people in every other country. All of them came to me and they said they wanted to talk to me about the subject of how much was enough to give the basic science. That was nonsense, what they really came to me for was to find out what in the devil the United States was doing. They had all imitated our science structure in the White House and here we had just done this.

SCIENCE AND TECHNOLOGY POLICY: ADVICE IN GOVERNMENT PANEL

D. Allan Bromley

In the time available this morning, I want to address only two specific topics that I happen to believe are important to the nation at the moment. The first of these problems that I see is the graying of the American scientific and technological community—something to which I have made my own contribution. The fact is, I do not see in the pre-college, K–12 educational system in this country anything like the number of future scientists and engineers that will be required to replace those that are increasingly at a level where, while they are still extremely productive, they are simply leaving the scene.

I hardly need to remind you of the results of the "Third International Mathematics and Science Study" comparing student performance. At grade 4, our students are competitive in the world. By grade 8, they have dropped down to the middle of the pack, and by grade 12, they are dead last in physics and second from the last in mathematics. I think that we as a nation have every right to ask, "What in the hell have we been doing to them?" We are spending more per student on education than any other part of the world, and yet this is the result that we have seen. There has been an enormous amount written about this rather sad situation, and I am not going to reproduce any of that; we simply do not have the time. But what I want to go back to are the reasons for this unfortunate and actually scandalous situation.

I remember in the prehistoric days when I was a college student. There were three groups that acted in a coherent and effective fashion to educate and, I dare say, civilize the younger generation. These were, first, the parents; second, the faith-based organizations (churches, synagogues, mosques); and last and most important, the teachers, a great many of whom were very dedicated and extremely intelligent women who, at that time, had no other career options open to them other than nursing. So we benefited from their teaching. All this has changed dramatically, as all of you know. Today there are so many single-parent families. There are so many sets of parents not really involved in their children's education. Faith-based institutions are no longer playing their old role, and the unfortunate thing is that the pre-college teaching profession is no longer respected and given the real status that the teaching profession demands.

Realistically, if we are going to address this question, we have to tackle this last one. If the students do not respect their teachers, it is quite clear that their interaction is not going to be what we might wish. Second, if the profession is not respected, it is extremely difficult, if not impossible, to attract really outstanding people for the next generation. Given that, what I would recommend is that we face up to the fact that we need to restore the respect of this profession. I would suggest, first of all, that we begin paying our pre-college teachers on a 12-month basis, as we do all of our other professions, on the condition that during the months when they are not actively teaching, they, in fact, increase their professional qualifications. In addition, although many people will say it is a ridiculous thing to say, we need to increase all the salary levels of all of our teachers. Many will claim that this will mean we are paying people vastly more than they are worth on any objective basis, but this is beside the point. What we are trying to do is to change the public perception of the pre-college teaching profession. The way to do it is through these two changes. Now, of course, it would require a very substantial amount of money, and I imagine that it would scare the political world completely out of the picture. What I am suggesting is that we pick one or two small states that have indicated a real interest in education and establish pilot programs there. If, indeed, these programs are as successful as I hope they would be, they will naturally spread to the rest of the country.

The second point I want to talk about relates to some degree to some of the material that Jack Marburger presented gave a marvelous foundation for remarks I want to make. I want to address specifically the role that people, members of the scientific community, really need to play in the national program of science and technology. In my view, the most serious fundamental problem that we have faced in recent years is the loss of the major corporate research laboratories—Bell Telephone, Hewlett-Packard, General Electric, and Xerox. These laboratories used to be the jewels of our entire science and technology enterprise. They are now being systematically dismantled, with the people and resources being distributed to the production divisions. More importantly, the time horizon of their research is changing from years and decades to weeks and months.

There are all sorts of reasons why this is happening, but unfortunately it leaves the question of who should do the long-term research that is absolutely essential in a technological democracy like ours. The two obvious candidates are the federal laboratories and the research universities. The research universities have the advantage that, by working in parallel with their research, they also educate and train the next generation of researchers and teachers. The disadvantage, and some of you may disagree with this, is that today there is no single spokesperson for higher education in the United States. Someone who has anything like the stature that James Conant (former president) of Harvard, or Kingman Brewster (former president) at Yale, or Donald Kennedy (former president) at Stanford possessed. Because there is not a spokesperson in the competition for long-term research responsibility, many scientists are convinced that the universities are, in fact, losing to the research labs. This is going to have important educational consequences.

I would remind you that back in 1996, the American Association for the Advancement of Science (AAAS) projected the funding situation for the next five years, 1995 to 2000. They predicted that research funding across the board would be cut by between 25 percent and 30 percent in constant dollars. This of course would have been a disaster. The first response to this was a small group of senators led by Phil Gramm (R-TX), who proposed that we have new legislation that would double the funding across the board for non-defense science in the next decade. The fact that this was not originally bipartisan held it up, and it was not until late in the cycle that the Gramm-Lieberman national research investment act of 1998 was proposed. Unfortunately, nothing happened in the Congress, but the appropriation committees that had been heading down this slippery slope of a 20 to 30 percent cut changed their minds and came through with an increase for basic research of 10.6 percent, which was remarkable.

In parallel with the work that was going on in the Senate, the American Physical Society, of which I happened to be president at the time, got together chemists, mathematicians, and astronomers, and put together a one-page statement of why we needed an increase of at least 7 percent in going from fiscal year 1997 to fiscal year 1998. We based this on two arguments. The first argument was that, as Alan Greenspan, chairman of the Federal Reserve Board, keeps repeating, more than 70 percent of the growth in our gross domestic product since World War II can be traced directly to implementation of new technology. Second, science and technology in many fields are much more closely interdependent now than they ever were before, so it is impossible to even guess where the next really important breakthrough is apt to occur. I do not want, in the time available, to go through all the legislative details, but a group that started out with only four professional societies was finally built through an enormous amount of effort on the part of the leaders of the original four professional societies to 110 professional societies representing 3.5 million scientists and engineers. When you walk into an office at either end of Pennsylvania Avenue and say, "I'm here representing 3.5 million scientists and engineers", they listen. The combination of the work that was done specifically in the Senate by

Gramm (R-TX), Lieberman (D-CT), Pete Domenici (R-NM), and Jeff Bingaman (D-NM), and then by Trent Lott (R-MS) and Tom Daschle (D-SD), really meant that, throughout the period from 1995 to 2000, we received 10 percent increases a year in the investment in fundamental research, at a time of real political pressure on the federal budget.

That being the case, it emphasizes that in our current situation, remembering that I use a slightly different number from Marburger's, if we consider the investment in research and development in the United States as a fraction of our gross domestic product, it is now more than 50 percent reduced from what it was in 1960. My firm belief is that, even under the pressures of demands from the military, homeland security, and all the other areas that Jack mentioned, President Bush has been able to continue his drive to double the funding for NIH over five years but has, under the present circumstances, rather de-emphasized all the other agencies. What this means to me, and what I am recommending to the scientific community, is simply that the time has come for the coalition of professional societies representing the scientists and engineers of this nation to come together and again make the case for federal investment in support of science and technology, recognizing that research and development are the drivers of our economy and that this is a time when we very much need a vibrant economy.

SCIENCE AND TECHNOLOGY POLICY: ADVICE IN GOVERNMENT PANEL

John Gibbons

The topic of our gathering is sort of this self-confessional on bridging the gap. I will try not to recount too much of my White House days, but reach back even further to my days in the Congressional Office of Technology Assessment (OTA) and other times of trying to help gather information for special studies, mainly in science and technology, and then transforming them into effective communication tools to people who need that kind of information in order to maintain our national progress. I did find out at OTA that analysis is okay, especially if it can be used to support your policy position, but the role was to try to raise the level of the debate, not influence, in a direct way. Sometimes that worked fairly well and other times not so well. Ultimately, OTA came under attack, I think in part arising from its findings with respect to space-based missile intercepts. Some people called it Reagan's revenge.

I left before OTA was disbanded in 1995, but I do tell the tale of a young man who wrote an essay on one of the world's great people. He won first prize. He said, "My essay is about Socrates who was a great person." And the essay goes as follows: "Socrates was a great man. He gave advice to other people. He was poisoned." So you have to be careful how you develop your advice. I have four areas that I thought I would mention to you that are relevant to this forum.

First, I would like to talk about dealing with complexity at the frontiers of science and technology. We know the enormous power of combining expertise across disciplines. It is showing up more and more in our economy, also in our research activities. Jack Marburger mentioned Harold Varmus. I remember one day in the Roosevelt Room when we were talking about the forthcoming federal budget. Neal, I am not sure you were in the room, but I do remember Harold Varmus being there, and NSF's budget came up. Neal did not have to rise, because Harold rose to defend the NSF budget and pointed out the enormous imperative to support that budget in order for him to fulfill his work at the NIH. He talked about the absolute necessity of bringing disciplines together—science, mathematics, engineering, and computations—in order to move ahead in any one of these distinct fields. It is a truism that is still under-appreciated in our country, and I think there some more work we need to do. This is terribly important.

The implications of the notion of combining expertise effectively, bridging disciplines, learning each other's languages, the way we think, and the way we work together, working in teams as well in individuals, does have revolutionary implications for higher education, for the way we organize and do research and development. We must work very hard at it. Our future in such areas as nanotechnology, climate change, molecular biotechnology, quantum computing, the technological development of new age energy supplies, and efficient use of energy, all depend, as we transition into the 21st century, on learning how to do this kind of high level integration of knowledge. We are a knowledge society, or at least we mean to be. But that society, is increasingly functionally illiterate and simply will not survive as a democracy unless we do something about it. There is a Disney theorem that I developed once known as "wishing will make it so." Wishing will not make things so. It will take a lot of hard work, interdisciplinary work. I remember in the old days of fusion research, it was called Project Sherwood. I am sure you remember Robin Hood, taking from the rich and helping the poor. In other words, it "sure would" be nice if it would work. I think the same thing goes with the way we loosely talk about a hydrogen economy now. Those of us in this room understand the enormous challenge and unknowns that we face in setting such a challenge. Maybe we should rename the hydrogen economy the Sherwood Project.

My second area is the conflict of time constants in our modern society. The focus of politics is largely self-constrained to short-term—days to decades. The world of climate change, population stabilization, demographic transitions, post carbon emitting energy systems, and biodiversity loss, has inherently long-term constants. These issues will take shape in more than half a century. How do we reconcile our priorities in both of these worlds, both of which are legitimate? But they get mixed up. We have not reconciled these two very different time constants. I remember reminding President Clinton that the notion of going to Kyoto with a 12-year plan for climate protection was ridiculous, because we have to think in terms of many decades for total turnover of capital stock when we move towards a sustainable, low carbon world. And he said, "You're absolutely right, but it won't work in politics." Anything beyond ten years is just totally out of range. We must begin something that has a leading edge. Of course, it has led us to great debate about how you begin a 1,000-mile journey. The notion of arithmetic is really important and we are not very literate in arithmetic. Bertrand Russell once said that mankind would rather commit suicide than learn arithmetic, and I think we still have that problem. We have to recognize the folly of ignoring long-term issues that have high inertia. If we ignore them until they become crisis issues, we will have enormous costs to pay. Adlai Stevenson, Jr., once said that man does not see the handwriting on the wall until his back is up against it.

The third area is the notion of 21st century security. I believe this needs more examination and better definition. Antonio Gramsci wrote that, “the crisis consists precisely in the fact that the old is dying and the new cannot be born; in this interregnum, a great variety of morbid symptoms appears.” We are facing morbid symptoms. Therefore, we need to think more carefully about what we mean by security, and what we mean by our collective process of trying to assure a better future, not only for ourselves, but for our planet and future generations. Huge investments are being pushed for nuclear weapons and elaborate Star Wars ideas for missile intercept but, comparatively, dribbles for effective intelligence, for constructive engagement, for stress reduction in terms of economy, religious conflict, environment, population, health, and other core issues. For example, I thought last night that it would be marvelous if we could take the PALS—Permissive Action Links—that have been so beautifully developed for nuclear weapons technology and apply them to weapons like shoulder-held and aircraft missiles instead of retrofitting every airplane with an antimissile system on board. Why cannot we take some of the things we have developed in the past that are now somewhat irrelevant to the future and apply them to the future in a more meaningful way?

My next comment, before you chase me out of here, is a challenge to Houston and the rest of the country. What about this business of man versus instrumented and robotic space futures? It is an issue for all of us, not just the space community and Boehlert’s Science Committee. Where should we go from here? I think we may be in a little bit of a trap, somewhat akin to Iraq. We somehow got into the mess without careful consideration. The questions now are: “How to get out of it; where do we go from here? What do we do in terms of the funding of our investments in manned space, now that we have learned so much about the whole process, its utility, especially man in space beyond Earth’s orbit?” Martin Rees, who is the royal astronomer in the United Kingdom, recently wrote an article in which he says, “Mars needs millionaires.” Namely, if Steve Faucet can mount high altitude balloon flights, millionaires can take over manned space exploration activities and let the rest of the public work on something a little more down-to-earth.

Now let me quickly close. I think there is a doubly unique role for science and engineering in our nation's future. The role becomes more important with passing days. The first is obvious—to create thoughtful options for society to be able to employ as we move through this 21st century, which is the century in which we must move toward long-term sustainability of the planet's biosphere. The power of the exponential dictates it. The second responsibility is to use our tradition and our background to inform society and particularly our political leaders. We need to raise the level of dialogue and debates and help give people a better sense of what the future might be. C.P. Snow, who railed against the gap between science and social sciences, said once said that, "a sense of the future is behind all good politics. Unless we have it, we can give nothing—either wise or decent—to the world." I think we have a very special responsibility, and Neal, I am so delighted that you have invited us to come here and wrestle with the problem of illiterates in a knowledge-based society.

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Neal Lane

This is an extraordinary meeting with people who really do understand science and technology as well as policy. I am indebted to my good colleague Jack Marburger for taking time out of what I know is a very busy schedule to be here this weekend as well as to my colleagues on this panel and other sessions of this conference. These folks just do not let up. They keep doing important work that is part of the message I have gotten here today.

Earlier in the year, I gave a talk at the Philadelphia meeting of the American Physical Society, but not on physics this time. I was asked to talk on "Benjamin Franklin, the first Civic Scientist." I promise I will not repeat that talk, but I will use the theme to say a few words about my colleagues here today.

Benjamin Franklin, of course, was a key figure in the founding of our nation. He was instrumental in moving our fragmented colonies to embrace the notion of unity and, ultimately, independence from England. His leadership and wisdom, his fame and diplomatic skills were critical in getting the French support in the fight for independence.

But what is generally less known about Benjamin Franklin is that he was a serious scientist. He is particularly credited, in the history of science, for carrying out careful experiments to understand the nature of electricity. He also mapped the Gulf Stream and did a number of other important things. He discovered that lightning was an electrical phenomenon, not the work of the devil. And he invented the lightning rod, which made him a popular figure in society, on both sides of the Atlantic.

Franklin, I think, was a good model for the notion of "civic scientist," something I have talked about since I first went to Washington. A "civic scientist" is a scientist who uses his or her knowledge, accomplishments, and analytical skills to help bridge the gaps between science and society. They do this in many ways: by advising and serving in government, by working in national laboratories or in industry to directly connect discovery with use, and by educating the general population about science and technology—what it is, and how it impacts people's lives. Benjamin Franklin was such a person. At one point, he was an advisor to George Washington; so we could say Franklin was the first President's science advisor. My colleagues who spoke this morning are perfect examples of "civic scientists," as are the other speakers on the program, as well as many of the people who are here in the audience today.

In today's world, science and technology impacts virtually every aspect of people's lives—our health, safety, education, jobs, entertainment, environment, our personal security and the security of the nation, how we get around and how we communicate with one another, how we entertain ourselves, how we live, and how well we live. The current pace of discovery and application shows no sign of letting up. Indeed, like the universe itself, it may well be accelerating.

In a democracy, the people need to understand what is happening around them that directly influences their lives and the lives of their families; most important, people need to have a voice in their futures. But there is still a big gap that we need to bridge. My message today is that, given all these things, we need more, many more, civic scientists. I include, of course, engineers, mathematicians, medical, and other technical professionals like the men and women you have heard from and will hear in this conference.

Finally, I would like to add a personal comment about my colleagues on the panel. One thing I learned from my mother a long time ago is to hang around with people who are smarter than you are, and listen to what they have to say. I called on all these good folks many times during my "sabbatical" in Washington. They helped me enormously to find my way around that complicated town and stay out of trouble.

I remember Bob Palmer, our moderator, was close to Representative George Brown (D-CA); we were all close to George Brown. There were many occasions when I was in trouble on the hill, and George Brown had to bail me out. Sometimes he did not know in advance what trouble was coming; he just trusted that I was doing the right thing and defended NSF and me. I have always been enormously grateful for that.

Guy Stever, as you know, served as NSF director for President Nixon and later as President Ford's science advisor. Guy Stever set the standards for all of us, and he did it during an important and troubled time of transition in government. At NSF, Guy Stever handled some very politically charged issues that threatened, in a very real way, the integrity of the agency. He did this with good judgment, incredible political savvy and personal skill. There is no question in my mind that the trust and respect the NSF enjoys today is due, in large measure, to the wise manner in which Guy handled the agency in that difficult time. He has written a wonderful book on his life in science, academia, and government, *In War and Peace: My Life in Science*.

Allan Bromley, distinguished nuclear physicist and science advisor to former President George H. Bush, brought many important innovations to U.S. science and technology policy, as well as to the process whereby the White House coordinates the activities of the many “fiercely independent” federal agencies. He pulled together the Federal Coordinating Council for Science, Engineering and Technology (FCCSET) process, he elevated the profile of the position and the office, and he also established the practice of bringing together science and technology ministers from the G8 countries, the Carnegie Group, twice a year—a most successful international effort (I heard Jack Marburger talk about the importance of this as well). It is an off-the-record, no staff, no communiqué kind of meeting, where people who trust one another and who agree on the importance of science, engineering, and technology can exchange views.

Let me comment on something Allan Bromley said. I had an experience at NSF, shortly after I arrived, when I was visited by presidents of various research societies, who explained how important their fields were and why we needed to spend more money on them. One consortium for life sciences and biomedical research said, “You need to increase the NSF funding for biology and biosciences by 20 percent.” This was at a time when the whole agency budget was maybe going up only 7 percent. And I said, “Thank you for you coming, but you’re not being all that helpful. What’s the matter with chemistry, physics, and math?” They responded, “Well we don’t know about chemistry, physics, and math funding.” I said, “Well maybe your members don’t, but the American Physical Society knows about physics, and the American Mathematical Society knows about mathematics. How about you getting together, trusting one another to advise on what the respective needs of the different fields are, and then come in and tell us what you think we should do? Then go to the hill and tell them the same thing.”

Those kinds of conversation did not, in themselves, do much. What did change the funding situation was the collaboration between the leadership of the various science societies that Allan referred to. It is extremely important and needs to go on, because these scientists are not competitive. When the budget gets to the hill, it all gets torn apart into the various appropriations committees. You could triple the NIH's budget, and it would not touch the NSF, and vise versa. They are not in the same funding bill. I think that is not widely understood, and we need to do a lot more to inform our own community about how that works.

Jack Gibbons, President Clinton's first science advisor, was without question a tireless defender of basic research at a time when all the political forces, White House and Congress, were pushing towards practical applications and economic competitiveness. They had the attitude that we have to solve this problem now, do not talk to me about the payoff of basic research in 10 or 20 years. Gibbons also championed timely policies on energy and environmental issues, especially related to science and technology. I think he gave the President very realistic advice on matters like climate change and Kyoto. Had it not been for his personal support, I would like to add, I would not have gotten to the NSF, I would not have survived there for five years even if I had gotten there, and I certainly would not have been able to serve as the President's Science Advisor in the White House. I benefited considerably from the outstanding team of men and women Jack put together in the OSTP. Most of them were there when I arrived, and many of them are in this room.

Jack Gibbons commented on security issues. I would like to add that there is a tension that we have to address between security and freedom. Earlier I mentioned Benjamin Franklin, who said, "Those who would give up essential liberty, to purchase a little temporary safety, deserve neither liberty nor safety." It is a tough issue and a tough call. I know Jack Marburger is helping us try to deal with this issue right now.

So finally, on our list of distinguished science advisors, in chronological order, is Jack Marburger. I think Jack is "doing God's work" at one of the most difficult times in our nation's history. I can think of no one more capable of doing this difficult job right now than Jack. He does it with wisdom, skill, and grace.

All these distinguished individuals, and other science advisors who were not able to be with us today, are examples of civic scientists, who, following distinguished careers, have gone on to serve the American people through their work in government and public policy, people who in fact try to bridge the gaps between science and society. The audience is also filled with "civic scientists," and it is certainly an honor to be with all of you today. I think Ben Franklin would agree if he were able to be with us.

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Discussion

Question: There have certainly been times in the past where science advisors have gotten very involved in international activities and have been very important politically to the presidents. For instance, opening China in the 1970s, where Frank Press was very active. Dr. Moniz talked yesterday about our activities with the former Soviet Union and the science apparatus that has engaged in an overarching political problem, it was more than a science problem. Given the status of United States in the world today and the charges of unilateralism that we face, whether there are opportunities we are missing today, science can play a real role, not just in furthering science but also in defusing political tensions and making real contributions. We heard a lot of talk yesterday about the need for greater cooperation and collaboration in the energy field, which is something that may require 20, 30, 40 years and therefore tremendous political leadership. Are there opportunities out there today where we could possibly use science and international collaboration on science to further broaden political goals?

Stever: President Nixon, despite all his other affairs, opened the Soviet Union. He visited, and he established a detente with them. I shared the science and technology exchange in that detente. There were lots of things we would not give them, but there was a lot going on. One of the great leaders there said, what we need to do is start something really big, like the best hospital in the world here in Moscow. Of course, this was going very well, although Nixon was going downhill very rapidly, he held on to that idea as long as he could. I remember one of the last meetings I had with him was with the Soviet representatives. We were meeting at the Oval office, and he came over to grab the representative from the Soviet Union, and he said, “If you have any trouble with this thing, you just tell Guy Stever, he’ll tell me, and I’ll fix it.” Unfortunately, the idea was dismissed after they invaded Afghanistan.

Bromley: Two things: first of all, Neal mentioned the Carnegie Group that we put together in the first Bush administration and that continues at the present time. That was very important in terms of providing a back channel between the senior scientific and technological representatives of all the G8 countries plus the European communities and the Soviet Union. Their activities grew and settled a very large number of difficulties before they became issues. So I think that a strong maintenance of contact at the higher levels of our respective governments is of enormous value.

Second is that I had the privilege in 1992 of presenting, on behalf of the United States, the idea for what has come to be known as the Megascience Forum. I presented it to the annual proceedings of the Organization for Economic Cooperation and Development (OECD) in Paris, and it was unanimously accepted by the 34 nations present. What it does is make sure that we do not make the same mistake again that we made with the superconducting super collider. We should involve our international colleagues adequately at the early stages of planning for major facilities, which take people to the frontiers of modern science. This Megascience Forum provides an opportunity to discuss the need for, the character of, and the funding of major facilities that will be built in the future. It has already worked in areas such as elementary particle physics, deep sea drilling, and there are more projects in nuclear, atomic, and molecular physics. I think it has a bright future—a facility larger than can be supported by a single nation.

Gibbons: I think the scientific community is representative of the most important engine that pulls economies ahead. By definition, it is of universal interest. Our community also, as Bromley just pointed out, is engaged in work that now transcends the capability of an individual nation to effectively move ahead with it, the so-called mega-science work. The scientific community is deep into issues that are inherently global. There is no boundary for global climate change or oceans productivities. One problem we have is that we frequently have to deal with people in the international relations business who are technophobes. I do not think they are so much technophobes as they are techno-illiterates, and unless we can raise that level, the problem will remain. Norm Neureiter has made an excellent start in the State Department with bringing in lots of scientists, where they are seen not as invaders and usurpers but rather as facilitators and assistants to the process of foreign policy. We need to keep up that momentum.

Lane: The developing world often puts science and technology higher on the political agenda. Joni, my wife, and I were in China a year and a half ago. I had meetings with the Chinese academy and gave a talk. We ended up meeting with the then-President Jiang Zemin, talking about science and technology. That does not happen very often in the developed world. There is a gap in the priority placed on science and technology in different parts of the world. As proud and happy as we all are to be in the developed world, the future of the globe depends on what happens in the developing world. And they recognize that science and technology advances are critical to their future. All of us, when we were in Washington, tried, as Jack Marburger is doing right now, to connect the economic issues, security issues, and all the other important issues that are not intrinsically science and technology but that depend on it. They all require international cooperation. The challenge is to get through all the political layers to get the story to the president, agency leadership, and the Congress. I think that we have to work harder to raise the priority for science and technology in this country and collaborate with other parts of the world. Norman Neureiter did an extraordinary job of trying to getting science and technology injected again in the State Department and in all issues of diplomacy. I think that is a perfect example of what we need to do much more of. The National Academies have supported that effort and thus helped make it possible.

Marburger: There are really two very important long-term trends that are currently intersecting. One is the globalization of the economy. The technology-based economy is becoming globalized. The workforce is becoming globalized. Our labor models have to take into account what is happening in other countries, in developing as well as already-developed nations. The other force is the emergence of new kinds of security threats to our nation and to others. There is no question that very difficult policy issues are emerging at the intermingling of these two kinds of issues: security and globalization of the technology-based economy. A good example of this kind of tangled issue is the export control issue. What are we trying to protect with our export control laws and are we increasing security or increasing economic competitiveness or decreasing them? It is a very difficult issue for us to grapple with, but it is having a profound effect on how we do science. The export control list, for example, is being used increasingly to trigger scrutiny of people coming into the country, people who can work on projects in our research universities. It is a side effect of our effort to protect ourselves in an increasingly globalized technology economy.

Question: In this conference, we have been addressing the question of the gap between science and society, a dialogue gap. I think it is somewhat easier in my mind to talk about the gap. It is more difficult to practice. Can you share your wisdom on how we might be able to practice it?

Lane: The last thing I have is any wisdom. What we all have is experiences with examples that work and do not work. What I usually say about these kinds of things is, in fact, what I believe: there is no magic solution. It is like working in the White House. You have an idea. You try it. It works. It does not work. You move on. You try another idea. You never, ever give up. It is all about people working together, people finding a common viewpoint and a common set of priorities, and then interacting with their constituents, with people they can influence so that the network spans out. The best-laid ideas sometimes just do not work, so you go to plan B and plan C and make sure there is no end to that planning.

OIL, THE MIDDLE EAST, AND THE U.S. RESPONSE, POST SEPTEMBER 11

A Push for Energy Breakthroughs

Edward P. Djerejian

When I joined the Baker Institute as its founding director in 1994, I knew that energy and environmental policy issues would be an important piece of our institute's work. Secretary Baker and I, with our long experience in the Middle East, understood first hand the direct impact secure energy supplies have on daily life and prosperity in America and abroad. I knew that, among the major challenges facing us in the 21st century, energy and the environment would loom large.

It has been 30 years since the Arab oil embargo spurred a quadrupling of the price of oil. The embargo inspired the industrialized West to undertake dramatic and important actions to prevent oil blackmail from recurring. Interest soared in the 1970s in science and energy policy, and we saw the birth of important energy technology research programs at our national labs and in our universities.

But, in part because of the diversification spurred by the 1970s' response to sudden oil insecurity, oil demand fell in the 1980s and, with it, the price of oil. Unthinkably, complacency set it. We cut science research budgets, dropped promising initiatives, and got back into large cars. Sadly, now 30 years after the 1973 oil crisis, the international community once again faces difficult energy challenges and is being forced back into introspection concerning the lack of progress where energy supply and use are concerned.

Oil price volatility has again experienced record swings, and the future of the Middle East, home to 60 percent of the world's known oil resources, remains with great uncertainties. We also now understand the broad environmental challenges that face us from the continued increases in the rate of burning of fossil fuels.

Beginning in May 2003, the Baker Institute began an exciting new venture with Rice University sciences: to explore more fully how scientific developments, including breakthroughs in the nanotechnology field, might contribute solutions to the global energy problem. To this end, the Baker Institute, in keeping with the long history of interdisciplinary research at Rice University, has joined forces with Rice's Center for Nanoscale Science and Technology, the Environmental and Energy Systems Institute (EESI), and the Rice Alliance for Technology and Entrepreneurship to prompt a broader national dialogue on science and energy policy.

Energy is not just a critical national concern to the United States but evidently a global one. War in the Middle East, the recent political disturbances in Venezuela and Nigeria, emerging environmental pressures – all these events underscore the need for new, more secure sources of energy. The rate of growth in energy demand worldwide runs the risk of outpacing affordable, clean supplies unless we can muster not only conservation and evolutionary improvements to existing technologies, but also revolutionary new breakthroughs in the energy field.

The September 11 attack on the United States has changed the geopolitical landscape in many ways. The U.S. response to the attacks has prompted it to forge new strategic relationships and undertake new military initiatives that have affected old alliances and linkages. This shifting landscape of international relations will have significant ramifications for the geopolitics of oil in the coming decades. Already, the terror attacks and the implementation of the subsequent U.S. "War on Terror" has thrown a spotlight on the inherent risks associated with heavy reliance on oil supplies from the Middle East.

American science and technology policy will have a pivotal influence on whether the world will become increasingly dependent on Middle East oil in the coming decades. As I mentioned, more than 60 percent of the world's remaining conventional oil reserves are concentrated in the Middle East. A quarter of these reserves sit in Saudi Arabia alone. The Middle East is currently supplying over one third of world oil demand.

This percentage could rise significantly in the future, depending on policies in consumer countries and on the pace of development of new resources and technologies. The U.S. Department of Energy, in one forecast, even predicts that the need for OPEC oil could rise from 28 million barrels per day in 1998 to 60 million barrels per day in 2020, with the majority of supply having to come from the Middle East, especially Saudi Arabia.

Iran, Iraq, Syria, Sudan, and Libya produce around 8 million barrels a day at present or about 10 percent of world oil supply. Saudi Arabia alone is responsible for almost 10 percent of world supply and holds a unique position in oil markets. It maintains the largest share of spare idle production capacity of any other nation in the world. The kingdom is the only oil producer in the world that can replace single-handedly, within a short period of time, the total loss of exports for any other oil producer on the globe. No other nation currently has enough spare capacity to claim this role. Saudi Arabia is also the world's largest exporter, in past years selling almost 100 percent more than its next largest export competitor, Russia.

Saudi Arabia's cushion of spare capacity, which represents almost two-thirds of all global spare capacity, has provided security and stability to world oil markets for two decades. But policy makers and analysts have questioned whether reliance on one ally, no matter how reliable and strong an ally it has been over the years, makes sense in today's changing world.

Political and economic reform in the Middle East faces formidable challenges. There is a huge gap between the agenda of the "political Islamists" and the existing "liberalized autocracies" in the Middle East – one that is not easily bridged. Many countries in the Middle East have gravitated into liberalized autocracy for concrete reasons having to do with both historical experience and current societal, cultural, and political realities. The region as a whole faces severe social and economic problems, as governments have had real difficulty finding the resources to provide adequate services for a growing and restive and, in some places, frustrated population.

The delicate compromise that now represents the status quo among the middle class, reformists, Islamists, and ruling regimes in many countries in the Middle East, if upended, could usher in prolonged instability long before it produces, if it ever does, peace and stability. Even the history of our own country demonstrates the potential volatility of change.

In the aftermath of September 11, the United States is engaged in a major struggle to expand the zone of tolerance and to marginalize extremists, whether they be religious or secular, whether they be Muslim, Christian, Judaic, Hindu, whatever. The role of public diplomacy has taken on a critical importance in the effort to understand, inform, engage, and influence the Arab and Muslim world.

I have just returned from three months of travel in the Muslim world and intensive work in chairing the U.S. Advisory Commission on Public Diplomacy, that Secretary Colin

Powell asked me to undertake. This was a private sector advisory group that was mandated by Congress. We realized in our deliberations the urgency to bring about a transformation in the way the United States communicates its values and policies abroad. Such an effort will take a commitment of more substantial resources, larger numbers of skilled professional personnel, and better utilization of modern tools such as the internet, translated materials, and educational outreach. It is critical to our national security that our policies and our values be accurately portrayed in the international arena and that our enemies who choose to spread inaccurate claims about our intentions and actions be countered with accessible, meaningful, information and dialogue.

I cannot overemphasize how important this challenge is because, based on our visits to the Muslim countries this summer, we came back with a clear perception that we, the United States, are not in any way significantly present in the daily discourse to date, and dialogue on what America is about, both in terms of its values and its policies. This is something that, in a time when we are indeed engaged in this battle of ideas, has to be remedied. The administration is mandated to report on our findings and recommendations by October 31, 2003, and Congress has also stated that it is not going to appropriate funds to the executive branch on public diplomacy until their reaction to our report is in its hands. This is a serious issue that Washington has now seized on.

U.S. global leadership on energy and the environment is a major cornerstone of this effort of public diplomacy. The United States simply needs to show that it cares about the fate of the world's disadvantaged and that we are dedicating our plentiful resources to improving their future in concrete ways: by enhancing access to health care and medical solutions to challenging diseases like HIV-AIDS and by offering solutions to shortages of clean water, affordable energy, food, and education. Lack of access by the poor to modern energy services constitutes one of the most critical links in the poverty cycle in Africa, Asia, and Latin America.

Despite great advances in oil and gas drilling techniques and progress in renewable fuels, more than a quarter of the world's population has no access to electricity today, and two-fifths are forced to rely mainly on traditional biomass—fire wood and animal waste—or their basic cooking and heating needs. Indoor air pollution from this traditional energy source is responsible for the premature death of over 2 million women and children a year worldwide from respiratory infections, according to the World Health Organization. Without a major technological breakthrough, well over 1 billion people will still be without modern electricity in 2030, and rural women and children will still be barred from activities that can lift them out of the cycle of poverty by the need to collect daily biomass resources needed to survive. We cannot continue in the United States to be blind to the grave challenges affordable, clean, energy supply poses for such a large portion of the world's population.

It is our opinion at Rice University that a solution to the global energy problem will require revolutionary new technology, as well as conservation and evolutionary improvements in existing technologies. Advancement of nanotechnology solutions can be an integral component to solving the energy problem. Breakthroughs in nanotechnology open up the possibility of moving beyond our current activities for energy supply by introducing technologies that are more efficient, inexpensive, and environmentally sound. The benefits of such technology will not be confined to the United States or the developed world; indeed, its impact will be greatest for the world's poor. We are working on an initiative and we have had a conference with Dr. Rick Smalley, a Nobel laureate here at Rice, on the role of nanotechnology and energy especially in mid-century.

As you continue your deliberations today, I urge you to consider how we might improve public understanding of the challenges that face us in the areas of science and policy, especially in the areas of energy and the environment, and how these challenges link directly to the issues of national security and perceptions in the Muslim world that I have mentioned briefly in my remarks today. Without this public awareness, we cannot hope to muster the kind of financial resources and scientific effort that is needed to tackle the problems that face us. We must inspire young Americans of all backgrounds that a career in science offers not only the opportunity to make a contribution in the fight against poverty, disease, and environmental degradation around the world but also a means to enhance our national security in an increasingly dangerous world.

Sometimes, as I am entering the Baker Institute, I am impressed by the activism that occasionally bubbles up among the young people here on the Rice campus. That passion needs to be tapped into the laboratory, into policy studies, into public service by the clear and firm articulation of the important role science and technology development can play in providing a more promising, sustainable future for our planet.

EDUCATION AND TECHNICAL WORKFORCE

EDUCATION FOR A WORLD BASED ON SCIENCE AND TECHNOLOGY

Shirley Malcom

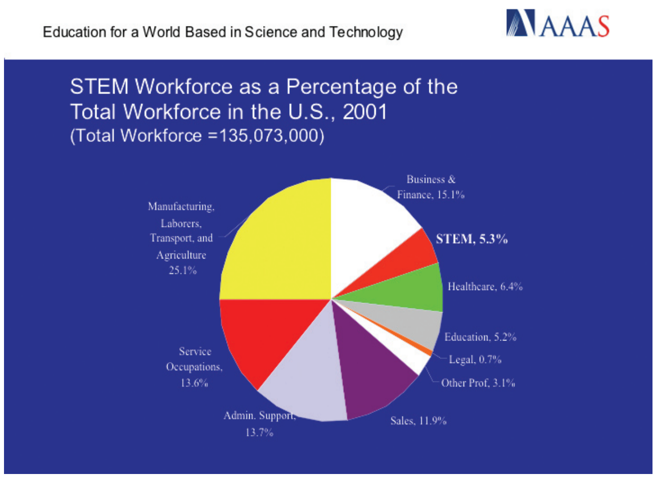
I am going to spend my time talking about the situation for education in science and technology in the United States. This does not mean that the international situation is unimportant. I had an occasion a couple of months ago to attend a conference in Alexandria, Egypt, with panel member Bruce Alberts. I met a young woman, an observant Muslim, who was a scientist. She said to me, "We've got to figure out a way to get better education for young kids, because, quite frankly, I think that we are in a race between ideology and reason and, right now, ideology is winning." Last year, we had an education conference in Rio, and among the attendees were two Iraqi scientists who talked passionately about the problems in pre-college education by describing the fact that the teachers were not well qualified or prepared to teach science in a way that was exciting to children. They noted that the textbooks and other materials were not adequate for the work that had to be done. There was a real problem, they said, with regards to the public understanding of science and technology, and I said, "Now, which country are you from?" Then I have another friend who comes from a less-democratic country whose aspiration is that children will be educated in such a way that they are able to have a healthy skepticism that will allow them to move more quickly towards a democratic structure. Those are the kinds of aspirations that I heard articulated from some of my colleagues in the international community as we move around discussing shared concerns about education.

I think what we have heard in this conference has convinced us that science and technology are enormous components of the developed world in which we live, but they are also a large component of the issues for the developing world, and perhaps, offer solutions to help raise the standard of living and the quality of life in those places. The question is: What kind of education do we have to provide in order to do that? Certainly it has to include a real grasp of the power that one receives from science and technology.

There are three kinds of human resources challenges that we face in the United States. The first challenge is to ensure that there is an adequate base of scientists, technicians, engineers, and mathematicians—the STEM people. You cannot operate or move ahead without them. The second is to provide a scientific and mathematics base that is adequate for other related fields such as health care. The third challenge is to educate the rest of the people with ample science and mathematics so they are able to live and work in our country.

One of the things that I think a lot of people do not realize is that scientists and engineers are only this small percentage—5.3 percent—of the workforce (Figure 1). That translates into about 7.2 million people. It is not just scientists we have to be concerned about, but we also have to consider the needs for science and technology in the other sectors such as business and finance, manufacturing, and health care.

Figure 1



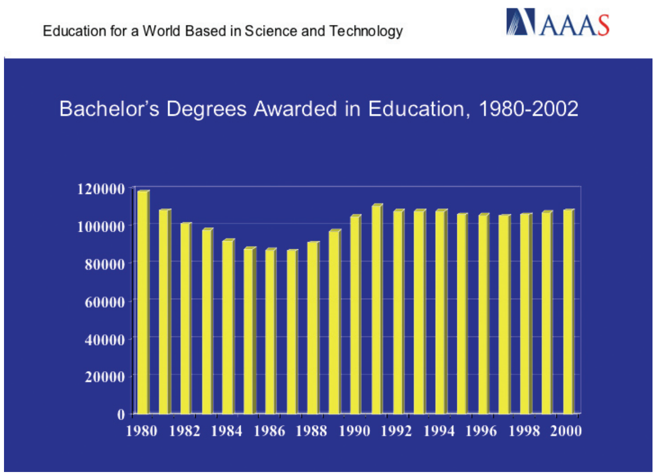
In terms of the percentage of bachelor's degrees in STEM fields compared with other fields, there is not much change. The most dramatic thing that you would see is that we are down in the physical sciences and engineering. Figure 2 shows bachelor degrees awarded in the physical sciences. One of the things that you do see is that in the 1980s there were more physicists and chemists than there were in the 1990s. So you have changes in the distribution by field. The biological sciences have expanded greatly, which you could have predicted given increased investment in biomedical sciences. The computer science field is interesting. Computer science degrees increased in the early 1980s and then fell rather rapidly. One of the things you may not know is that the high number of degrees awarded to women was in 1986, and that after that time, women's participation in computer science dropped like a rock. As a matter of fact, if you look at this decline, just looking at 1994 by comparison, you lost over 18,000 degrees between 1986 and 1994. More than 8,000 of this decline was among women. It is this kind of analysis that makes scanning the science and engineering workforce very difficult, because you have to understand what the motivations are for different fields and groups. In health professions, we are likely to see continued growth over time because both the need and the market are there.

Figure 2

Then there is a question of the rest of us: the teachers, the lawyers, policy makers, and the consumers of science and technology. I thought it was interesting that personnel in the State Department were sometimes more unaware of many of the issues that are going on that connect to science and technology. Increasingly, international affairs are an area where knowledge of science and technology is absolutely critical.

Figure 3 is a graph that really ought to be frightening for most of us because we have a very flat production of degrees in education. True, secondary level teachers, in many cases, now have to get degrees in a subject field and then have to get additional training in education. But right now there is a question of how we are going to replace all the people who are retiring. The average age of teachers is high (around 43 years old), and so this remains a challenge for us. A lot of people are asking: "Where did everybody go?" There has been some movement into business, but it really does not account for where everyone went.

Figure 3



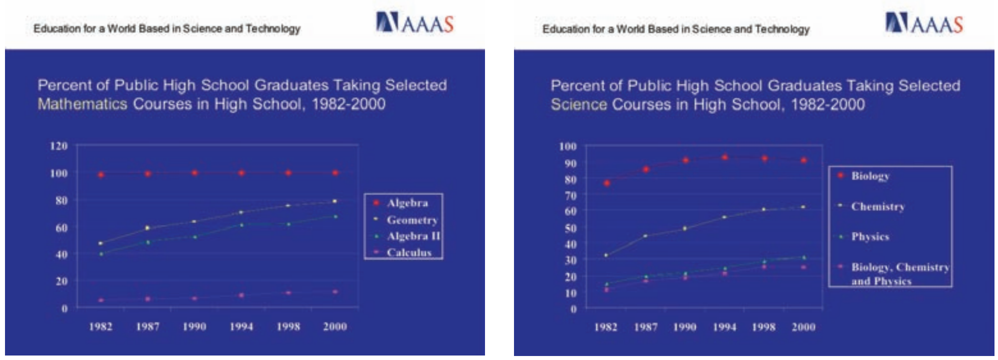
There are a lot of challenges in K–12 education. The first is that the education pathway for the citizen and the scientist is initially the same. At the third, fourth, and fifth grades, you cannot tell who will be a scientist. You cannot separate scientists from the other disciplines, and therefore you have to make sure that whatever quality is delivered is suitable to allow them to still make choices. I think this is the part that is actually quite frightening. Many students do not get any science instruction at all in their primary years.

The second challenge is that the size of the talent pool decreases over time and its composition changes. The capacity of the system to provide an appropriate high-quality education is limited and the components of the educational system are poorly aligned. The pieces do not fit together and this is a problem that we must all work to address. What I mean by the fact that the size of the talent pool decreases over time is that there are some courses that, if you do not take them, it is very hard for you to become a scientist or engineer.

As you see in Figure 4, almost everybody takes algebra, but do not take that fact on face value. They have something called algebra, but it is not necessarily the same class everywhere. As the level of the mathematics goes up, the percentage of the high school students who take it goes down.

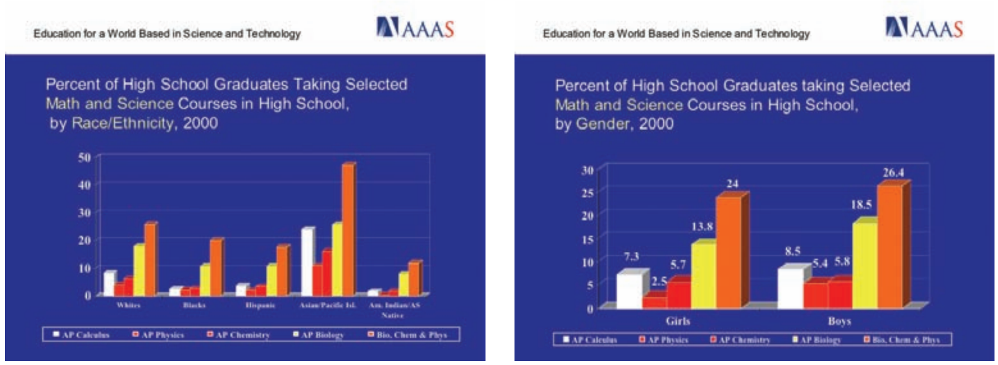
The same thing is seen in the science courses. For the most part, everybody takes biology. Or I would say that everybody takes something called biology; it is largely natural history and includes very little about modern biology. Very few take a course that includes elements of cellular and molecular biology, and the teachers who are there cannot teach it at a level to include these elements. We are seeing a real increase in the percentage of students who take physics, but it is still in the 30 percent range, and I want you to note the students who have had all of the above, which is what you are likely to need if you are to consider these students as part of the talent pool for science and engineering.

Figure 4



Now, Figure 5 is the percentage of high school graduates taking selected math and science courses in high school by race and ethnicity. You will note how the composition of this pool actually changes demographically; this is the same kind of graph broken down by sex.

Figure 5



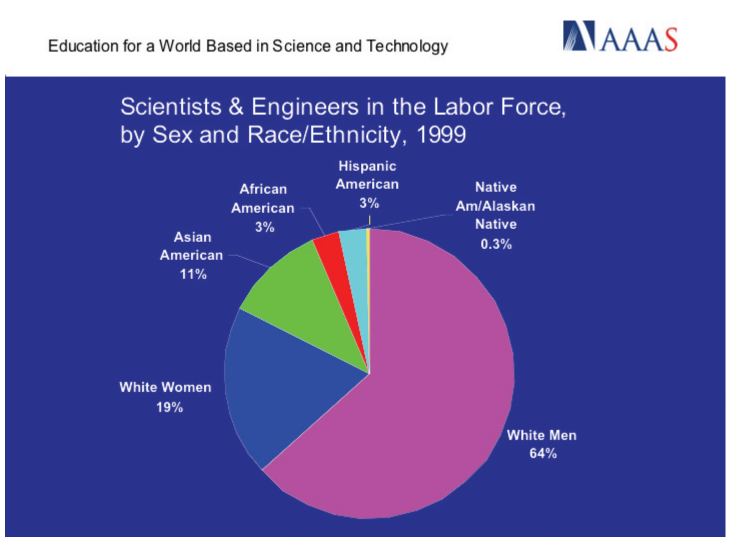
While I am quickly reviewing this material, you have to understand that there is a long story here, and that every component of the story is absolutely essential to bring someone out the other end of a pathway to produce a scientist or an engineer. There are at least two collegiate challenges of education. The first one is that those of us who are even taking courses in the sciences or engineering tend to live in stovepipes and have very little opportunity to see outside of whatever our major is. We end up without a coherent view of what science is. We can end up being scientifically illiterate in the fields where we are not trained. This is, I think, a major problem where we have a blind spot. The second issue is scientific, technological, and quantitative literacy as the component of a liberal education. We have not really begun to address this in a way that we have to. In many ways I had a better liberal arts education than the person who is an English major, because I had to take their field courses while they did not have to take mine.

At the graduate level, we have the mismatch between graduate education and career opportunities and the mismatch between training experiences and skills that are needed for jobs beyond academic. The third element that I really did not talk about was the science for teachers. It is embedded in that liberal education component.

I want to move from the education side to the workforce development side. We keep having this question pop up on a regular basis: Do we need more scientists? This is a question that I will attempt to address. The second challenging issue is the composition of the STEM workforce. And finally, the third is the nature of the education and career development.

Bromley mentioned before, the age distribution of scientists, and I want us to look at this very carefully. I think the major issue here is that, even among people who are older, there is a question of keeping their skills up to date, and that too is a workforce challenge. Figure 6 is a chart of scientists and engineers in the labor force by sex and race and ethnicity.

Figure 6

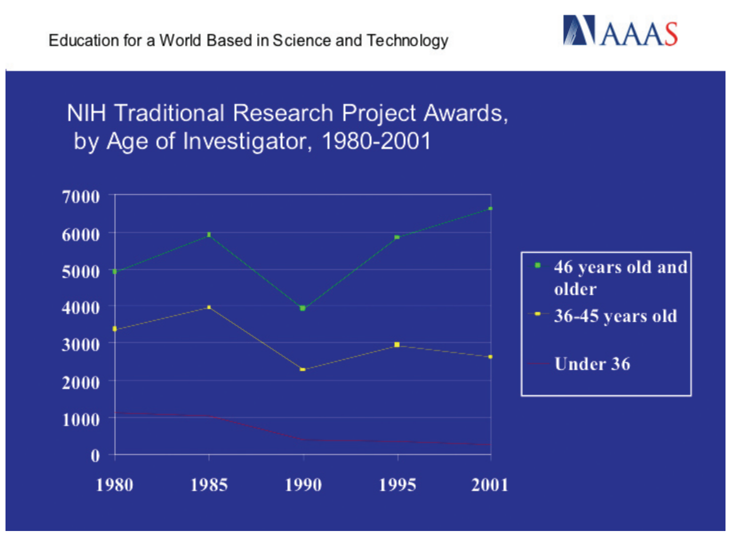


It shows what you would imagine, that this community is dominated by white males, which is fine, except that this is a decreasing part of the overall population of students who are coming from our school systems. If we look at places such as Texas and California, we already see school systems where the majority of students are among those groups that have the lowest participation and weakest traditions in science and engineering.

This demographic challenge is real, and it is something that we all have to face. There are challenges in education and career development. I mentioned one before which was the mismatch between education and work-place skills. Another is the lack of cross-sector experiences—when you work in a university and you do not have an opportunity to see what science looks like in other places, such as the national laboratories or industry.

The third challenge, which I consider to be a really serious issue, is the lengthening time to independence. I am going to actually take these issues in reverse order. Concerning lengthening time to independence, one of the studies comes from the NIH. Figure 7 shows the distribution of research project applications by the age of the investigator.

Figure 7



Do you see anything wrong with this? The NIH did not mean to have fewer and fewer applications from young people, but sometimes our policy produces these kinds of effects. They ended mandatory retirement, so people stayed in the system for a lot longer. This resulted in a growing time to independence. People are in postdoctoral positions. There are a lot of people in non-tenure lines who cannot apply for grants on their own. They lack the skills and have not been prepared to actually work independently. This is occurring in a time of unprecedented increases in the NIH budgets.

The questions that we have to ask ourselves are: “Do we need a targeted program for new applicants? Is it reasonable to expect that a new applicant is going to be able to compete with a person who has been doing this work for 35 years?” If we do not, in fact, bring young people into the system, we will pay in the long term. This is a question that we have to begin to raise.

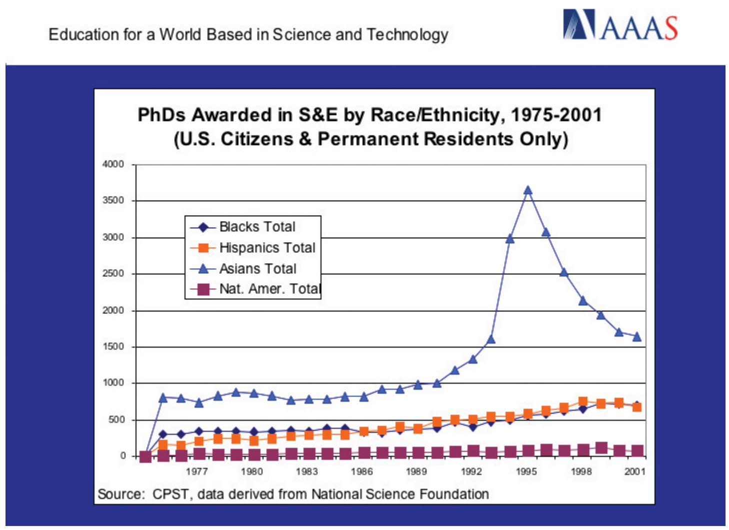
The second question was whether there is a shortage of scientists. There are hot spots where people are needed right now: bioinformatics, nanotechnology, and other emerging fields. But Teitelbaum, in his paper that actually takes this issue on, talks about the whole notion of unemployment rates. He says that unemployment rates are higher for scientists than they have been. In times of shortage, you usually see increases in salaries, and we have not. In times of shortage, we get importing of talent and exporting of jobs, and we got that even when we did not have a shortage. We have to realize that there are limits to the models of supply and demand, and this is not something that is just easily available to a labor market, economic analysis.

There are issues here that we really have to consider. The first is quality: There are never enough excellent scientists and engineers. The second is demographics: There is no oversupply of African-American, Latino, and Native American scientists and engineers. And the third problem is that even the scientist and engineers generated do not always have the skills and the know-how that is needed.

Diversity is the issue, and that is something that is going to be harder and harder for us to address. First of all, we have small numbers, a persistent achievement gap, and a political climate that is anti-affirmative action, which makes it more difficult for us to target groups for action. These students tend to go to different schools for their early preparation. How do we make sure that they are exposed to the experiences that they are going to need to become excellent scientists and engineers? We need these students for at least two reasons. The first is the faculty of the future. The students of the future are becoming more diverse. The faculty needs to become more diverse. Second, business and industry have realized a long time ago that there is a business case for diversity that is clear and unassailable.

We are beginning to see women catch up, more in some fields than in the others, with regards to Ph.D. production. Figure 8 is a graph of science and engineering degrees awarded to all minorities including Asian-Americans.

Figure 8



The numbers are low, with totals for each group well below 1,000. To provide some context, at the peak there are probably 36,000 degrees overall. So you can kind of get a sense of the numbers that we are dealing with. Our policies do affect what happens to the numbers. The major issue is that we cannot just get people in the programs; we have to keep them in. We cannot just keep them in; we have to promote them. We have to provide an opportunity for advancement for leadership because they have to have someplace to go.

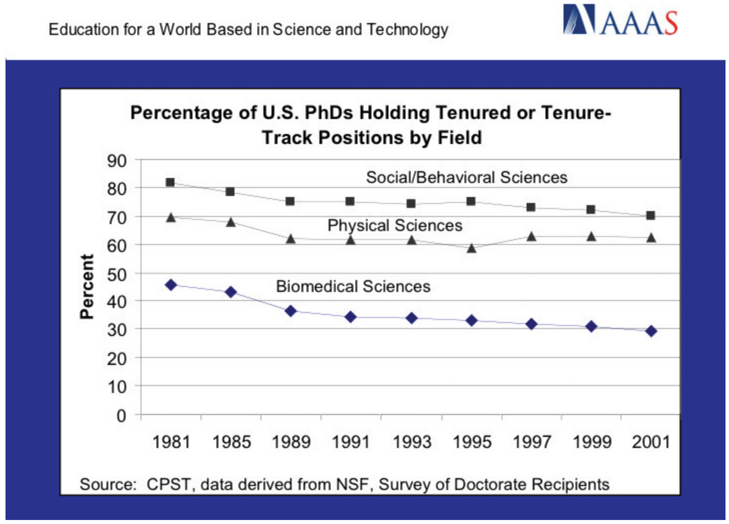
So what are the policy implications? In K–12 we have a challenge because of the national need for scientists and engineers, but we rely on the distributive system of production. You cannot manage the distributed system of production unless you deal with shared goals and agreed-upon standards. We also need reliable measurements to determine if the goals are being met in the distributed capacity, and we did not have any of those.

The challenges to capacity building are many, and I cannot even begin to give a complete list. This is a sample: the shortage of quality teachers in STEM fields, inappropriate curriculums, inadequate textbooks, insufficient funding, and laboratories that have not been refurbished since the post-Sputnik investments. Another problem is poor assessment. The reason that this is critical is that right now we have the "No Child Left Behind" law. The law requires testing in reading and mathematics and in two years we are supposed to test science. I do not have a lot of faith in the math assessment, and I will have even less in the science assessment because it is a matter of what kinds of skills we are actually looking at. Are we looking at the accumulation of knowledge, or are we looking at the ways of thinking? This is going to be a challenge for all of us.

We have policies with regard to college that are based on an outdated model of the make-up of the student population. Everybody does not go to college at age 18. We are not addressing the issues related to non-traditional students, part-time students, community colleges, and rise of propriety schools. We are not dealing with issues of distance learning as opportunities for technology education.

With regards to the Ph.D., we have real problems with the lack of full disclosure of the opportunities outside of academia. One of the things that I want to mention is the integration of research and education, in which Neal Lane invested a lot of his energy and capital. That is really where all of this is going to pay off in the long run. We have created responses to some of these problems such as professional science Masters programs supported by the Sloan Foundation to try to broaden the skill base. In AAAS we have tried to provide ways for students to find out about alternative careers through Science's Next Wave, or MiSciNet. Within NSF, there is a series of programs trying to address some of these challenges that we face.

Figure 9



I want to move to my last element, and that is the postdoctoral position. What new skills do you get in the third postdoc, and why did you not get them earlier? The fact is that we have people spending many, many years in postdoctoral positions, commonly in the biomedical sciences, and this is not of any value to anyone, them or us. These are people with adult responsibilities, possibly with families, where the salaries are low. This is a real problem, and we know there are differences between the behavior in the physical sciences and the biological sciences. Let us look at the real salary implications of some of this (Figure 9). We are beginning to understand what a disservice we are actually doing.

This is something that the federal government can actually do something about. They can mandate minimum salaries, they can require benefits, and they can limit the number of postdocs. I think that we may be closing in on that time. When it comes right down to it, I think that this is the bottom line: Do we see students as products of the work that we do, of the research that we fund, which is the spirit of the integration of research and education, or do we see students as by-products? We just happen to push them out along with the research. We have got to move from this notion of by-product and really understand the need to provide students with the skills that they are going to need to provide us a future in science and engineering. I think that the challenge is clear and so, in some cases, are the pathways.

EDUCATION FOR A WORLD BASED ON SCIENCE AND TECHNOLOGY

Discussion

Question: I want to add another dimension of challenge—one that impacts leadership of underrepresented minorities. In the collegiate level, there is diversity within the levels of the schools. We see the Asians and African-Americans; we see them in the minority institutions. If we want to get the leadership to the national level, we cannot have this aggregation. The second thing is, I will go back to K–12 and "No Child Left Behind." In fact, we know we started here in Houston, Texas, that kind of activity. What we basically see is that we make sure that everyone gets to the point that they can tie their shoes. But we have to have the accountability that there is diversity at the front of the pack in the third, fourth, and fifth grade. Because, when you get behind the pack, even though you are not left behind—you can tie your shoes—you are not going anywhere.

Malcom: I think that the points you raised are good ones. I agree with you absolutely that people are distributed very differently among different institutions. At the undergraduate level, for example, Hispanics are disproportionately represented at community colleges in Texas, in California, and in other places. You have students—African-Americans—who go on to get Ph.D.'s that are disproportionably coming from historically black colleges and universities. These institutions are carrying more than their fair share, but they are not necessarily receiving the resources that will allow them to basically bring the students up to the point where they can compete. Leadership, you are right, comes out of a certain set of institutions, and unless we can get these students into those institutions and out with good Ph.D.'s, we are not going to have them available to serve in the faculty or serve in the policy community as they are going to need to in order to address the needs of the future.

Question: I have a less global question I want to ask. Go back to the slide where you showed chemistry, physics, biology, and math all on the same one—the question of quality and who takes what. Leon Lederman has pushed, as you know, a new curriculum where physics starts the education in high school in sciences, which is followed by chemistry and biology. I am just curious if you have any results to that experiment?

Malcom: I will comment on it. It is going to be a hard thing to do, because we have very few people teaching physics now, teaching it at all, and then there is the challenge of teaching it well. That is the issue: capacity. Now, let us separate capacity on the one hand, and "does it make sense" on the other. It absolutely makes sense. If you teach physics, first as conceptual physics, you actually allow students a much more hands-on, grounded experience with the world. Then you moved the chemistry. When I was a high school biology teacher, I spent much of my time teaching chemistry because most of my students had not had it. Therefore, they had a less rich experience. There is some interesting data. When Leon raised this issue with me, I said, "If you go and you find places that are doing this, I want you to look at the distribution of students in those places." And what he found was that everybody tended to stay in the system. You did not have the drop off among girls and minorities as you see here in this slide. There are real equity issues. Biology has a certain kind of pull on its own. If you are able to keep people in the system, the longer they stay in the system, the longer they are in the game. The minute they leave the system, they are out of the game. And I think that is the kind of experiment—action research—that we need to do to really give it a fair chance, to see if we can provide preparation for teachers—maybe teachers in physical sciences who can be moved into teaching conceptual physics. I think that is not a very large jump that has to take place.

The university is the only group that produces teachers—the colleges and the university. Higher education has to step up to that and know that you reap what you sow. In fact, if you put out teachers who do not have the grounding in the subject, they will come back as students.

Question: Could you outline for us the number of high school students that go into a higher education and those that graduate with a bachelor's degree or higher? Hispanics, for example, which represent a median over the last 30 years, of the 30 percent that go into our education, only 4 percent get a B.S.

Malcom: If you look at the numbers in engineering, I think it was the National Action Council for Minorities in Engineering that estimated that, of about 500,000 minority students who finished high school, only 32,000 are finishing with the requisite courses that will allow them to choose to go into the field of science and engineering. Out of that they get 7,000. There is a huge drop off.

Question: Do our policy makers understand the economic and global competitiveness of this problem?

Malcom: All of us in this room—and this is the choir in here—sing all over the place that there is, in fact, a relationship between the education of today's children and the viability of tomorrow's economy. I think that some people have got it, and we are getting more and more allies, but it is something that can slip off the table because there are more pressing immediate problems. Just like energy and global climate, the issues of education are long term. It takes years and years to make one of these things called a scientist or engineer.

Question: Here at Rice, we have had an experiment for the last few years of creating Masters in science teaching where we try to get more content to our science teachers. It is kind of a struggle because on one hand, the science disciplines say, "Well that's not a science degree, so you're cheapening the Rice degree program," and then the other people say that it is really not an education degree, because they are not doing research in education. Do you see that as a good place where we can improve the content and quality of our teachers?

Malcom: I think that is one place. I agree with MRC Greenwood. We are going to have to stop sending out people that are in immediate need for professional development. But we have a number of people who are in the schools already, and one of the things we have to do is provide them with a set of options with regard to how they get professional development. Not all of them have the resources, the energy, or the impetus to come back for a degree. I like Allan Bromley's idea of a 12-month contract, with having the opportunity for people to have professional development, and I also like the idea of online and other kinds of options being explored much more aggressively. But I will say that at the bottom of every option that I put forward is the need for the scientific community to embrace the problem and own it—for scientists and engineers and mathematicians to become much more engaged with teachers. No teacher wants to do a lousy job. We have done a lousy job by them by sending them into a situation where they do not have the tools always to do a good job. So I think that any kind of option or alternative that can be presented that allows people to learn more science, learn more about the pedagogy that is appropriate for the students, and to learn what works for what kinds of students in what kinds of circumstance, more power to you.

EDUCATION AND TECHNOLOGY WORKFORCE PANEL

Science Education and Technical Workforce

Duncan Moore

I want to follow-up on some of the data that Shirley Malcom showed this morning, but I will present the information a bit differently. In Table I, I have listed the top 19 majors in the United States.

Table I

Table I – U.S. Higher Education Data (2000-2001)
Bachelor's Degrees

Field	Number	Change from Previous Year
Business	265,746	3%
Social Sciences/History	128,036	1%
Education	**105,566**	**-2%**
Psychology	73,534	- 1%
Health Professions	73,490	-6%
Visual/Performing Arts	61,148	4%
Biological Sciences	60,553	-5%
Engineering	**58,098**	**- 1%**
Communications	58,013	4%
English	51,419	1%
Computer/Information Sciences	41,954	16%
Liberal/General Studies	37,962	5%
Multi/Interdisciplinary	25,999	-5%
Protective Services	25,211	1%
Parks, Recreation, Leisure	19,565	2%
Public Admin & Services	19,447	-4%
Physical Sciences	**17,979**	**-2%**
Home Economics	17,777	0%
Mathematics	**11,674**	**-3%**
All Others	91,000	-2%
Total	**1,244,171**	**1%**

Source: Digest of Education Statistics, 2002,
National Center for Education Statistics (http://nces.ed.gov);
Table 255.

There are approximately 1.2 million people who get baccalaureate degrees every year. The most popular major is business. You can see that almost a quarter of the people get business degrees in this country. As you go down, you see education, which Malcom alluded to earlier, has about 100,000 degrees. What she did not show is that when you survey these people who get their degrees, a year after they have left their undergraduate degrees, they are not teaching. There are only about 60,000 of them that are teaching.

As we start to figure out all the numbers, that is an important thing to do. Looking further down you see engineering with about 60,000 and the physical sciences are down at 18,000. Now that only tells us a little about the picture. What is really interesting here is that, if you break out the engineering numbers, you find out there are only about 12,000 electrical engineers graduated every year. If you look at the number of physicists that graduate every year, it is about 3,500. We are graduating fewer people with the baccalaureate degree in physics than we did before Sputnik. It is not particularly surprising to people in graduate education and in the physics-based engineering fields that there are not many applicants. That is where we get most of our applicants, in graduate-level physical sciences. So the numbers have been cut in half in the last 15 years.

One of the things I would like to point out is one of my favorite majors here: parks and recreational leisure. We are graduating 20,000 people in parks and recreational leisure. If you are a university president, like MRC Greenwood, looking at how to allocate her resources, she wants to be in a growth industry, and clearly parks and recreational leisure is, not electrical engineering. So we better think about how we deploy our resources.

Another thing I want to show is the Ph.D. and graduate degree problem (Table II).

Table II

Table II – PhD and Other Professional Degrees 2000-2001

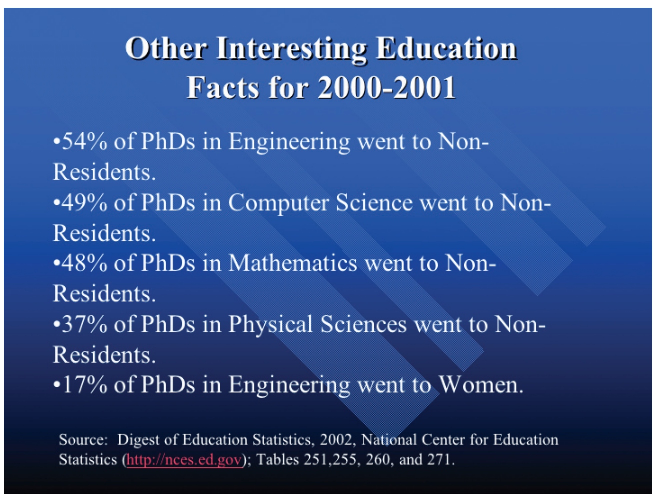
	Number	**Change from Previous Year**
PhD and ED	44,904	0%
JD	37,904	-1%
MD	15,403	1%
Pharmacy	6,324	12%
Divinity	5,026	-18%
DDS	4,391	3%
Chiropractic	3,796	0%
DVM	2,248	0%
All Other Fields	4,615	2%
Total	**124,611**	**0%**
PhD and ED:		
Education	6,716	-2%
Engineering	**5,558**	**3%**
Psychology	4,659	8%
Biological Sciences	4,600	-5%
Physical Sciences	3,976	-1%
Social Sciences/History	3,930	-4%
Health Professions	2,855	7%
English	1,506	-7%
Theological Studies	1,469	-11%
Business	1,180	-1%
Computer Science	**768**	**-1%**
All Others	7,687	4%

Source: Digest of Education Statistics, 2002, National Center for Education Statistics (http://nces.ed.gov); Table 254 and 260.

We are graduating about 45,000 Ph.D. and education degrees every year. If you look right below there, we are graduating about 38,000 lawyers. So we are getting one lawyer for every Ph.D. If you think we are going to have a less litigious society going forward, you are kidding, because they want to be employed too. Now if we start looking by discipline, engineering has about 5,600 engineers with a Ph.D. So we graduate about six lawyers for every Ph.D. in engineering. So they are always going to beat us, there is no doubt about that.

The other thing I want to point out here is that this is not a typo. There are only 768 people receiving Ph.D.'s in computer science today. That is an amazing number. When we look at the data for this, half of them are foreign students. The one where I think there is a real problem is that only 17 percent of Ph.D.'s in engineering go to women (Figure 1).

Figure 1



Now from an international standpoint (Table III), I think this is a kind of interesting issue. What I have done here is ranked the countries by the number of baccalaureate degrees they give. By far, the United States graduates more baccalaureate students than anyone else in the world, and to normalize them, we compared the number of those to the number of 24-year-olds. That gives a measure as to how well-educated the population of that country is on some line.

Table III

Table III – Bachelor's Degrees

	Bachelor's Degree		Engineering BS	
	Number of Degrees	**% of 24-year olds**	**Number of Degrees**	**% of BS/BA**
United States	1,199,579	35.3%	60,914	5.0%
India	750,000	4.8%	29,000	3.9%
Russia	554,814	25.6%	82,409	14.9%
Japan	532,436	30.1%	103,440	19.4%
China	440,935	2.2%	196,354	44.5%
United Kingdom (Short)	258,753	36.0%	22,012	8.5%
Brazil	245,401	8.2%	-	-
South Korea	204,390	24.7%	45,145	22.1%
Germany (Long and Short)	197,151	21.4%	32,663	16.6%
Mexico	191,024	9.4%	21,358	11.2%
Total	**4,574,483**	**-**	**616,123**	**14.0%**
Worldwide Total	**6,781,885**	**9.6%**	**868,340**	**12.8%**

Source: Science and Engineering Indicators 2002;
National Science Foundation; Table 2-18.

I got interested in this is because of China and the competitiveness issue. Where is the Chinese economy going over the next 15 to 20 years? How well-educated is the population, and what are salaries likely to be? I said, "Oh gee, this looks like no problem." But then I looked at the number of engineering degrees. What you see, and this does not include physics and chemistry, are pure engineering degrees. What you see is that China graduates almost 200,000, more than three times the number of engineers we are graduating in this country. To put this in some perspective: It is not surprising that they want to launch men into space.

In the United States, the total number of engineers is about 2 million, so it will not take very long for them to accumulate as many engineers as we have, and they are going to be a lot younger. The demographics are going to be much more favorable, if we assume that the best years in engineering and science are the beginning years. So, if we look at that as an international competitiveness issue, this is a very big deal.

So the question is: What are we going to do about this? I think we all agree there is a problem in K–12 education, but it is very mixed. We have some school districts that are very excellent in this country, where taxpayers are willing to pay a lot of extra taxes to support the schools.

There are two types of teachers: science teachers and teachers of science. So teachers of biology, chemistry, and physics are teachers of science, but most kids have a science teacher who is teaching English, math, everything else until they are at least in sixth grade. The demographics, as Malcom pointed out this morning, show that we are losing them in the fourth and fifth grade. Why is that? One of the things we have learned is that guidance counselors are telling high school students, “Oh, you are going to go to college. So you are not good in science and math. You could be an elementary schoolteacher.” Well that is probably not the direction we want to be going.

Malcom also mentioned this morning the issue of community colleges. The community college system has not gotten the respect it deserves. In New York State, 45 percent of the people who become teachers started in the community college system. If we do not get the students, while they are still in the community college system, interested in science and math, it is not likely they are going to change when they switch over to the four-year schools.

So there is a real issue that we have to address in the community colleges of how we are going to do that. I believe we have a huge marketing problem. I know those of us in this room do not want to hear that it is a marketing problem, but I really believe it is. I have a great example of that. Penn State for several years has run a science camp for fifth and sixth graders. At the beginning it was called a camp for chemistry, and there was one for physics. The fifth and sixth graders did not want to do that. They did not know what chemistry was; it was a fear factor, something they take in high school. You get some of the good students whose parents are pushing them, so what they did was they changed the name of the camps. It is no longer called “Chemistry,” it is called “Potions.” And the physics one is no longer called “Physics,” it is called “Quidditch.” For those people who do not read Harry Potter, it is probably the most well-received book among that age group. Is the course content any different? No. Do they dress up a little bit? Yeah, the teachers dress up in various types of costumes and that sort of thing. They get the students engaged in doing the same experiments. They have one based on the TV series “CSI.” It is a forensics course. What we have to do is figure out a better way of packaging what we are already doing. We need to get some more marketing experience in here, and we are not doing that.

The other thing that we need to think about, which Neal is a big advocate of, is speaking to the general public. We spend a lot of time talking among ourselves, but if you want to do something really scary, give a talk to a Rotary Club in a rural environment. That is a really interesting experience. The point is, we are not delivering our message to the people who are really voting; we are delivering it to ourselves, and we are not the problem. One of the things we have to do is have something in our pocket that we can pull out in the middle of a talk and ask, “You know what this is? This is a pill camera. You swallow this, and it takes 50,000 photographs of the inside your small intestines.” And people say, “Oh wow, that is science.” They start getting it, and they say, “Oh, now I know why we should be supporting the science and engineering enterprise.”

EDUCATION AND TECHNOLOGY WORKFORCE PANEL

Thomas Kalil

Good afternoon. What I would like to discuss is the importance of national science and technology initiatives as a mechanism for increasing support for research and development. From 1993 to 2001, I had the good fortune to work with Dr. Neal Lane on a number of science and technology (S&T) initiatives, including the National Nanotechnology Initiative (NNI) and the "Information Technology for the Twenty-First Century" initiative. I believe that these initiatives are an important tactic for increasing federal investment in research and development.

The request that the science community traditionally makes is, "Give us seven percent more money than you gave us last year." This is not a terribly compelling argument. The White House Office of Management and Budget (OMB) has an allergic reaction to the notion that there should be some arbitrary level of support. Furthermore, by the time budget decisions reach the White House, high-level decision makers are making tradeoffs between competing presidential priorities with very tangible outcomes. Should we have 100,000 cops on the street, or improve the security of our foreign embassies, or reduce class size by 25 percent in the early grades? Since almost all of the decision makers are non-scientists, to say that the budget of science agency X should increase by 7 percent is not something that attracts a great deal of support.

I think the second reason that these initiatives are important is that many of them have the potential to be in areas that Donald Stokes has referred to as "Pasteur's Quadrant." That is, fundamental research motivated by considerations of use. These may be areas of research where it is easier to capture the public imagination. The third reason is that by focusing on a problem or area, you have the potential to increase support for interdisciplinary research, which, as Jack Gibbons mentioned, is particularly important.

A fourth consideration is that these initiatives often build support for increases in the core budget. During the last couple of years in the administration, we were able to get 15 percent increases in the NSF budget. We would not have been able to do that in the absence of all the excitement around new areas of research such as information technol-

ogy and nanoscale science and engineering.
Having said that, I do think that there are a number of risks with the initiative process that we need to be conscious of. One is that not all areas of research are going to lend themselves equally well to initiatives. I cannot see the president of the United States using his State of the Union address to unveil a new initiative in string theory, for example. The second is that you do have the potential to have a "disease-of-the-week" phenomenon, where areas are chosen on the basis of political whims or fads as opposed to serious priority setting. The third difficulty is that it is a lot easier to launch these than it is to sustain them over a long period of time.

The fourth problem is that there are 13 different appropriation subcommittees. The Executive Branch can develop a well-prepared, multi-agency initiative and it may not have any real impact on the decision making of the individual appropriation subcommittees. Appropriators are making trade-offs between the budget of the Veteran's Administration and National Science Foundation, or between important water projects in their districts and the Department of Energy's Office of Science. Finally, the United States often has "divided government," in which the White House and Congress are controlled by different political parties. Occasionally, Republican members of Congress seemed to have the view that, "If you guys are for it, we must be against it," irrespective of merits.

John Holdren argued that scientists and engineers should tithe their time and energy to contribute to the public debate on S&T funding. I think that developing new S&T initiatives would be a great activity for "civic scientists."

There are a number of questions that White House staff typically had to answer before we had any chance at all of building White House and ultimately congressional support for a given science and technology initiative. First, what is the rationale for government involvement? Why does the private sector not do it? Second, what is the return on investment from past investments? This is one of the arguments that enabled us to make a strong case for the increased investment in long-term information technology research. We could point to the huge impact that DARPA and NSF investment had had in information technologies such as the Internet, RISC, electronic design automation, user interfaces, and mass storage, for example.

Third, what are the potential outcomes or grand challenges that might be associated with an increase in funding? Scientists and engineers may have winced when they heard the

President talking about storing the Library of Congress in a device the size of a sugar cube, making materials that were stronger than steel with a fraction of the weight, or detecting cancerous tumors before they are visible to the human eye. However, I can guarantee you that the National Nanotechnology Initiative (NNI) would not have been launched if we had just argued for an across-the-board increase in disciplines like condensed-matter physics and materials science.

The fourth issue is the need to develop a detailed research agenda associated with the initiative. Fifth, one needs to describe what might be achieved or accomplished at different levels of support and determine how much the federal government is already investing. The sixth issue is the modalities of support. What is the appropriate mix between intramural and extramural research? What is the right balance between support for individual investigators, small groups, centers, and shared facilities? The seventh issue is the consideration of policy instruments beyond research and development. In the context of clean energy and energy efficiency, previous speakers have discussed the importance of information campaigns and tax incentives. Finally, it is important to know whether the government has the capacity to manage an increase in funding in this area, and whether there is a research community worth investing in.

For example, Henry Kerry and I tried to work on increasing support for long-term educational research. One of the problems we encountered was that the Department of Education did not have a stellar track record in managing high-quality education R&D. It reminds me of a Woody Allen story in which the two elderly women are talking to each other, and one says, "Boy, the food at this place is really terrible." And the other one says, "Yeah, I know and such small portions." That captures the challenges we face in increasing the quality and quantity of our nation's education research.

In the interest of sparking a discussion, let me briefly describe ten areas where I believe there is a strong case for increased federal investment. In all of these areas, there is already some level of activity, but I believe that more and can and should be done.

1. Create the scientific and technological foundations for affordable carbon-free energy sources that can scale to 10 to 30 terawatts by 2050
2. Invest in learning science and technology such that we have a rigorous understanding of what interventions actually improve student performance. This will require much more aggressive use of randomized clinical trials and the development of new learning technologies that will allow us to approach the

effectiveness of one-on-one tutoring.

3. Harness our scientific and technological know-how to address some of the challenges of developing countries—what Jeffrey Sachs has called "weapons of mass salvation." Currently, we are investing more in developing treatments for male pattern baldness than we are for AIDS, tuberculosis, and malaria. One can make an argument that we ought to be investing more in infectious diseases that are prevalent in developing countries.
4. Invest in research and development that would create the foundations for a sustained increase in productivity of three percent. If the United States experiences one percent productivity growth rate, standards of living double every 70 years. If we enjoy three percent productivity growth rate, it doubles every 23 years. What we need is not only new information technologies, but also new ways of organizing work and new ways of using technology.
5. Explore some of the non-health applications of biology. Currently, since NIH is our major supporter of biological research, we are under-investing in non-health applications such as bioenergy, bio-remediation, and bio-fabrication.
6. Develop the technologies for next generation bio-defense. How are we going to live in a world in which there is widespread capacity to create genetically engineered pathogens that are more virulent, resistant to existing vaccines and antibiotics, and may have long latency periods before we see any symptoms? How are we going to live in that world without large casualties?
7. Invest in e-science or "cyber-infrastructure." How do we harness advances in computer networks, scientific instruments, sensors, and software tools for collaboration and analysis to accelerate the pace of discovery in all disciplines of science and engineering?
8. Experiment with some of the proposals to expand the science and engineering work force that have been suggested by economist Paul Romer and others—such as significantly increasing the number of scholarships for people who pursue graduate education in natural sciences and engineering.
9. Develop alternatives to "silicon CMOS" (complementary metal oxide semiconductor) that will allow the semiconductor industry to continue doubling performance every 18 months. Today's silicon CMOS technologies may hit a brick wall after 2016.
10. Address issues of research grant size and duration. This is particularly important for the NSF, which has an average grant size of $120,000. If you are a faculty member with ten graduate students in your group, NSF can't really support

> a significant fraction of your research. A major effort to significantly increase the NSF budget is desperately needed.

In conclusion, I think there are two things that the research community should consider doing. First, organizations such as the National Academies, AAAS, and scientific societies should proactively propose and develop some of these new initiatives. Second, a group of leaders in the scientific community should approach some high-net-worth individuals to underwrite a well-financed, well-organized campaign to build White House and congressional support for them. The NIH doubling campaign was successful because a philanthropist supported a robust political campaign that included public relations, grassroots activities, coalition building, lobbying, and polling. These are the kinds of activities that are required to make support for these initiatives a reality.

EDUCATION AND TECHNOLOGY WORKFORCE PANEL

Joseph Bordogna

In thinking about what to say on this issue in terms of gap bridging, I decided to make some remarks that derive from a lot of questions and discussions we have been receiving in a sequence of NSF speeches on broadening participation. These questions and discussions tend to drift toward adjacent issues, which while important, take us off point and off focus, thus mitigating our efforts to broaden participation. We all recognize that greater diversity in the science and engineering community is vital to our nation's prosperity and security. We understand how including the full gamut of intellectual perspectives and talent gives us an edge in discovery and innovation. And we know that embracing diversity is the right thing to do, or in Guy Stever's words this morning, "It is indeed something we should do."

We can celebrate the clear progress we have made in many fronts in this area. Yes, there is more diversity in the science and engineering workforce compared to 30 years ago, and maybe more important now, there are some people who know how to make it more diverse in the future. There is no algorithm for it; they do it in different ways. We ought invest in them and accelerate their efforts. Even though we have made progress, the fact remains that years of dialogue and effort have not produced the surge in forward momentum that is necessary and increasingly urgent to reach our objectives. This is surely one of the significant "gaps" between science and society that is the theme of this conference. If we are going to "bridge" this gap, we need to be absolutely clear about our common aims, and then move decisively beyond agreement to collaborative action. How we get the job done is by no means straightforward. Our world, like the science and engineering of our times, is increasingly complex and dynamic. The challenge of diversity is no exception. Accelerating our efforts to meet this challenge will require, for starters, a refined and sophisticated posing of the questions we should be asking.

Keeping our antenna tuned to the need for action, I will offer some contrasting viewpoints that may help us clarify our strategy and vision. These contrasts suggest a subtle shift in focus, a reframing of issues that may provide a more useful context for effective action. In other words, I want to contrast what broadening participation in the science and engineering workforce is not about, as a way of suggesting what it is about. First, it is not about the total number of engineers and scientists the nation may or may not need. More and more frequently we seem to be distracted from our diversity goals by questions about trends and statistics. Do we really need more scientists and engineers? Is the demand for them really greater than the supply? Are our Ph.D.'s going to go begging for career opportunities in academe, government, and industry? What it is about is the need to include a larger proportion of women, underrepresented minorities, and persons with disabilities in the scientific workforce. Whatever the total numbers turn out to be, we need a robust and varied mix, and that means expanding diversity.

Second, it is not about the number of foreign-born students, scientists, and engineers who study and work in the United States. They have always been a source of strength for our society and economy and a way of lifting human potential globally. It is about fully developing our domestic talent. In our knowledge-intensive society, we need to capitalize all available intellectual talent not only to advance but also to keep our nation humming. Although we are doing better than we did 30 years ago, we have not seriously tapped our nation's competitive ace-in-the-hole (women, under-represented minorities, and persons with disabilities). Now we are playing catch-up in a very competitive world. We need to understand that diversity is an asset and, similarly, a valuable component of progress. An open door policy that educates and enables our own citizens to be contributing participants in our great democratic system, as well as continuing the successful policy of embracing those from abroad, will make us a genuine, welcoming nation for both talent from abroad and for our own nation's women and other underrepresented minorities.

Third, it is not about keeping businesses from going abroad. Science and engineering have always been international. In today's increasingly networked world, we are unlikely to staunch the flow of mobile and global enterprises into and out of our borders even if we wanted to. It is about educating scientists and engineers with a competitive edge. To be on the frontier of discovery and in the vanguard of innovation requires new capabilities and skills that are qualitatively different from production-line education that turns students into commodities bought on the global marketplace at the cheapest price. We want to create an environment that attracts an eclectic and diverse array of students to pursue studies in science and engineering and encourages them to stay on the course. We need a variety of learning paths that support creative, world-class scientists and engineers.

Fourth, it is not about demanding that our students learn more and more basic knowledge to delve deeper into a specialty. This is a good thing, but knowledge is changing so rapidly that sticking to this path alone could be a recipe for disaster. It is about providing students with additional capabilities that will enable them to work across boundaries—to handle ambiguity, to integrate, to innovate, to communicate, and to cooperate. These are components of a holistic education that not only suits the science and engineering of our time, but also thrives on diversity. The differences in race, ethnicity, and gender that are found in our society are a positive force to engender this creativity and dynamism. The divisions we experience will only hold us back and sap our energy until we erase them.

Fifth, achieving our common goals is not about working from the bottom up or the top down. We are frequently asked, “What is the National Science Foundation doing to solve these problems?” NSF is certainly a willing and able player, as it should be. We are very seriously committed to broadening participation. In fact, our statutory mandate explicitly includes this responsibility. This means taking action, not just talking. We identify and support innovative programs to broaden participation, but we are by no means capable of addressing all the issues single-handedly. Broadening participation is about working together. When we understand that diversity is essential to prosperity, it becomes the nation’s responsibility, and that includes all of us. Every sector and every citizen has something to offer. We will realize our goals sooner if we all work in harmony.

It is the varied, richly textured and shaded fabric of diversity, not any single thread, that provides durability and strength to our science and engineering enterprise and thus to our nation. Diversity, once given scope and opportunity, has the potential to shape, to transform, and to drive our future for the better. We need to spend less of our intellectual capital worrying about supply and demand and invest more in getting on with the task of transforming our nation’s diversity into our strongest asset. The prize here, the treasured trove of diversity, is clearly worth the effort.

EDUCATION AND TECHNOLOGY WORKFORCE PANEL

Science and Education: The Challenges Ahead

Bruce Alberts

I want to talk today about how the National Academies have been focusing on educating our citizens more effectively—both to create better scientists and engineers and to prepare better citizens. The National Academy of Sciences was incorporated during the time of Abraham Lincoln. As a private organization in Washington, we needed a charter from the President to exist at that time. For reasons left to history, this charter specified that we could only exist as an honorary association if, in addition, we were willing to advise the government on any matter of science and technology. The famous added phrase—that we must do so "without any compensation whatsoever"—is why we are a great service organization today with some 6,000 volunteers who serve on advisory panels at any one time. We call ourselves the National Academies, a name designed to include our operating arm—the National Research Council formed during World War I—as well as the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The last three organizations are honorary societies with a total of about 5,000 members.

The National Research Council has allowed us to include lawyers, teachers, and whoever else is needed on our committees, which at their core are scientific but also incorporate grassroots information from the front lines. We are useful to Washington only because we are completely independent in all of the advice that we give. Even though the government pays our costs for each of the studies it requests, we do not negotiate the answer to the questions the government poses. Instead, we release the final report to the government and to the public at the same time on our website.

We think of ourselves as preparing two kinds of reports. Most focus on how we use science for policy. For example: What does science tell us about the dangers to humans of different trace levels of exposure to arsenic in drinking water? Other important reports focus on policy for science, which is what I am talking about today. Our most difficult policy-for-science report ever was the *National Science Education Standards*, a task generated by the 50 state governors in 1989, led at the time by Governor Bill Clinton. The governors felt that education from kindergarten through high school was faltering in this country, and they requested national voluntary standards for each basic core subject. The question of who would be assigned this task bounced around for quite a while. Finally in 1991, with the support of the NSF and the Department of Education, the National Academies accepted responsibility for the science education standards.

I came in midway to the task, in 1993, when I began my first term as president of the Academy. I cannot tell you how difficult this job turned out to be, except to say that I must have spent nearly half of my time over the course of the next two years working on this project. The next-to-last draft was commented on by 18,000 reviewers, and their reviews took nearly a year to accommodate.

In the end, the *National Science Education Standards* turned out very well. Their guiding principles are: science is for all students, learning science requires active engagement, and school science should reflect professional science. Basically, the report called for a revolution in the way that we have traditionally taught science, both at the K–12 level starting at age 5, and as I will emphasize later, in the first two years of college. Different standards are presented in different chapters. The one chapter I would like everybody to read is only 25 pages long. This is the “Science Teaching Standards,” which makes it clear that teaching is an incredibly difficult and important art.

Several people today have already mentioned that everything depends on the quality of our teachers and how we support them. I agree. Moreover, we have to be more sophisticated about what we think good teaching is; simplistic ideas abound. Because we are talking about a revolution, the National Academies have produced a series of supplements to the report. One of the most important ones is about inquiry. What is inquiry, and how does it look in the classroom at various age levels?

The motto for this whole crusade is “every child a scientist,” by which we mean that every child should have the ability to use logic and evidence to reason and argue like a scientist—not that he or she will turn out to be a scientist. Figure 1 is a photograph of the Einstein statue in our front yard in Washington, covered with children. This sense of comfort and accessibility is the image we all want for science, but to achieve this goal there is a very large gap to fill.

Figure 1

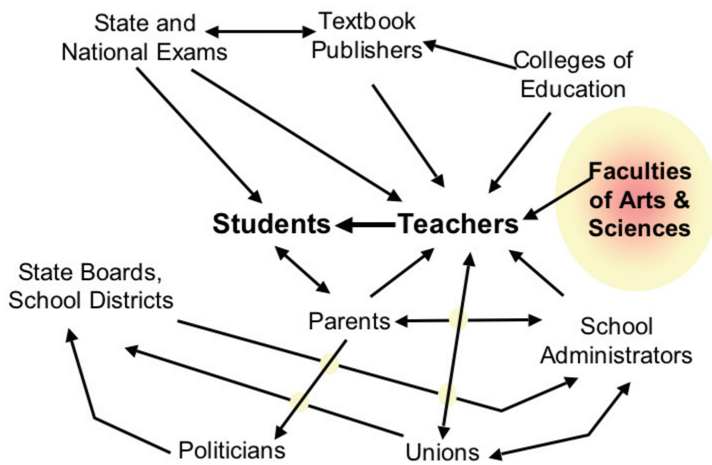
I would argue that one of the best places to fill the gap is in our classrooms. We have to make science exciting and accessible in our schools. We know how to do it, but we do not do it in many places. The good news is that inquiry-based science education precisely fits the needs for workforce skills that have been widely expressed over and over again by U.S. business and industry. So we have a strong potential ally in this movement, if we can mobilize business leaders and help them become sophisticated enough to be effective. Here is a quote from Robert Galvin, former CEO of Motorola.

> While most descriptions of necessary skills for children do not list "learning to learn," this should be the capstone skill upon which all others depend. Memorized facts, which are the basis for most testing done in schools today, are of little use in the age in which information is doubling every two or three years. We have expert systems in computers and the Internet that can provide the facts we need when we need them. Our workforce needs to utilize facts to assist in developing solutions to problems.

Motorola should know a great deal about this issue. They had been hiring many high school graduates who were not qualified to work on their factory floors. As a result, they set up their own education system for employees called Motorola University. The quotation therefore comes from long experience with the education that Motorola needs for its lower-level workforce, not to mention for its leaders.

The bad news is our inertia. We have incredible inertia in our education systems and, as I will emphasize, the universities are a major part of the problem. Most of the scientific societies have also been too passive here. It is not just others who are at fault. We are all in this together. Figure 2 presents a diagram of our education system that comes from a report of the National Academies published several years ago.

Figure 2



As a chemist, I see this as an equilibrium diagram that explains the inertia – one that also makes the point that we cannot do anything by fixing any one of the actors in the system. Nevertheless, many scientists will blame almost anybody (for example, the textbook publishers or the unions) except themselves for the sad state of science education in the United States today.

I want to emphasize the faculty of arts and sciences at the university level, where the science professors (I was one for 30 years) think that we have nothing to do with this issue—that the K–12 system is somebody else's problem. Of course, when you think about this more carefully, as emphasized by Malcom, it is at the college level that we define what science teaching and the focus of science education should be. I claim that we at universities are misdefining both of these by our poor performance in our early science courses.

I am a biologist and biology may present the worst case because every year the amount of information in biology goes up by perhaps 10 percent, and we still try to teach all that in one year. Textbooks are enormously thick and heavy. The way that we define science in our big lecture classes has nothing to do with the definition of science that we came up with in the *National Science Education Standards*. At a minimum, we need to fix the first few years of college, if we are going to accomplish the badly needed revolution in science education at lower levels in the United States. This is the conclusion that I have reached after trying many other approaches over the course of the last ten years.

We urgently need to change to an inquiry-based teaching of science and its relation to society for all college students and to convert those cookbook science laboratories, which we have been forcing students through for 50 years, into an experience with science as inquiry. Especially at our research universities, all students should have some involvement with inquiry during their freshman year, just to acquaint them with what we really want in the way of educational performance. This fits a vision for our introductory science courses published by the Academy several years ago; the NSF published a similar report at the same time.

The hardest group to change in the whole education system may be the college professors. Because I was a department chairman at two different universities, I should have known this before I came to the Academy. How are we going to create change in college science departments? I realize now that we need to get more evidence. For example, we need to know exactly what the effects are of the large lecture courses in biology. Why are they causing so many of the best students to drop out of science? In the first few years of college, we are losing half of the students who had thought that they wanted to major in science. These are not the worst students; they are students with talent equal to those who stay in science. If the science faculties had clear evidence of the effects of their teaching that we could present to them in a meaningful way, I believe that my former colleagues could be mobilized to teach differently.

A major mission at the National Academies is to “make a science of education.” An important report that we produced to begin this new focus was called *How People Learn: Brain, Mind, Experience, and School*. It basically takes the last 30 years of what we have learned about learning in academia—in psychology departments, and elsewhere—and asks: “What are the implications of what we know from that scholarship for our schools?” Strangely enough, this translation of knowledge had not generally been made, showing how completely the world of academia has been disconnected from the world of our schools.

To create a continuously improving educational system, we will need a much more effective system of education research. I completely agree with Tom Kalil. We need to focus much of this research on classroom settings. There has to be much more respect for the scholarship that helps us understand what is actually happening in our schools. It is critical that, as in science, we accumulate a commonly accepted body of knowledge of what works and why, based on confirmable evidence. Otherwise we will continue to have what we have today: School systems where the teachers are jerked around in every direction by the latest education fad. Every new leader seems to have his or her own new program. You cannot build an education system on politics, and that is what we are trying to do today. I am from California; I should know.

So what is good research in education? The National Academies recently published an important report called *Scientific Research in Education*. You may find it hard to believe, but this issue has generated a very hot political debate in Washington. This is amazing, who would have believed it? Our report should set the standard for this important topic to help get us all back on the same page.

Among the research that is urgently needed is that on the effects of teaching science as inquiry in school classrooms. Part of the reason why there has been resistance to moving our agenda forward is that we do not have enough evidence about what works, why, and how we can do a better job of implementation—as well as what the effects are on the long-term attitudes of children and their abilities. We have lots of anecdotes; we need to do a much better job of collecting solid, objective evidence.

I want to end this talk on a personal note. I care deeply about this problem. I was in San Francisco for 17 years, having a wonderful time as a professor at the University of California, San Francisco (UCSF). A special nominating committee of Academy members phoned to ask me if I wanted to be considered as a candidate for president of the National Academy of Sciences. This was in spring 1992, and I said, “No!” In the fall of 1992, they phoned me again and said, “We know you did not want to be considered for this job, but we chose you anyway. Please just come and talk to us about this possibility.” In part, they had chosen me as president because of my strong interest in science education. I had been working with the San Francisco schools, and they suspected that, because of this interest, I would move to the Academy in Washington if offered this full-time job.

Well it has been ten years, and I only have two years left to solve this education problem, so I hope that all of you out there are going to help me because there are a lot of problems left to solve. There are three major issues at the center of this debate that keep me up at night. First, there are the problems of testing. We all believe in accountability, but to a large extent, nobody differentiates between one kind of test and another. If you test in fifth grade for science learning with a multiple choice science fact list, as we are apparently doing now in the public schools in San Francisco, then you will get the kind of science teaching that will drive everybody out of science. The students will hate it. That image I showed of all the kids on Einstein, you can forget about it. We will remain where we have been for far too many years. If we instead had a different kind of science test, one that tests for how students can solve problems, we might be able to drive the system in a productive way.

You should know that every state is required to have a set of high stakes science assessments in place by the 2007-2008 school year, as part of the "No Child Left Behind" federal legislation. But who is giving feedback from the real world of the schools so that the people who make education policy will know whether our new testing requirements are working or not? There is no effective system of feedback from the shop floor operating in our education system today.

My second major issue is that the U.S. business community has been quite ineffective in advocating for its own interests. Most business leaders remain largely ignorant about the two different kinds of science education I describe. They certainly want more and better science education, but they do not discriminate between multiple choice tests for accountability and the kinds of testing and science education standards that would produce the workforce that Robert Galvin needs. This leaves science education vulnerable to political and economic forces that continue to buffet the system, thereby continuing to threaten our long-term national security. I just came back from ten days in China. That nation has its act together and is moving in a uniform, focused direction. They are using our *National Science Education Standards*, and they may have printed more translations than we have printed in English. Their leaders have placed science and technology at the center of China's economic and political development, from President Hu Jintao on down. We need to wake up and get our act together here in the United States.

The third and last issue that keeps me up at night is that our best science teachers, and there are many of them out there, need to have much more influence on the education system to which they have devoted their lives. Current trends – the kind of multiple choice testing I am talking about or their work loads—will drive our talented teachers into more lucrative and respected careers. Their influence and wisdom are needed at every level—from the national level all the way down to the state and district level. Right now, our best teachers have almost no voice in any of the decisions that are made about our education systems.

For the past few years, a pressing question for me has been: How can we change this terrible state of affairs? In my view, providing a strong new voice for our best teachers may be the only way that we can inject long-term stability and wisdom into education decision making—the wisdom that will be needed to create the continuously improving educational system that our grandchildren deserve.

My latest experiment is the establishment of a Teacher Advisory Council at the National Academies. This Council is composed of some of the best teachers in the nation, 12 of them, each spending at least half of their time in a classroom. This group of incredibly energetic and wonderful people was the reason why I was late getting to this meeting. We had our own meeting in Washington of the Council, and I promised that I would be there. The mission of this group in the broadest sense is to provide a much stronger voice for our nation's best science, mathematics, and technology teachers in national education policies. This will also require connecting these kinds of teachers to business and industry leaders, so we can get all our forces in line to move our education systems forward in an effective way.

The Teacher Advisory Council of the National Academies has thus far met about four or five times. They are now recommending that we help to form associate Councils to provide a voice for teachers at the state level, where most education policies are made, as well as to better connect our states to the national group.

I end with an advertisement for our website, www.NationalAcademies.org. We have devoted a lot of resources to making all of the reports we have produced—whether science for policy or policy for science—freely available for everyone to read on the Web. And we are making a special attempt to connect the resources we have, including those for teachers, to the great national effort to improve education everywhere.

EDUCATION AND TECHNOLOGY WORKFORCE PANEL

Discussion

Question: I have been involved with a group called HENAAC, Hispanic Engineers National Achievement Awards Corporation, which is one of many groups dealing with the issue of K–12 education and diversity. My question is: Is it time for some coordination, some leadership, some identification of winners and losers, some investment and improvement assessments and so on? And, if so, who should provide that and who can provide that leadership and coordination?

Bordogna: That is exactly what I was talking about with this priority area or initiative. This is an effort to integrate across the many different investments by lots of different people. It has three parts to it: one is “integrative institutional collaboration”—a fancy name for what you are talking about. This is to get the money in a competition by having those with a track record integrate somehow and compete and then trying to get the best of them to accelerate their productivity in this area. The second part is “faculty for the future.” We are talking about K–12 through the professoriate—we decided not to say “teachers,” we decided to say “faculty” to get them to mix together well in a variety of ways. And the third has to do with research that was talked about here by the Academy of Sciences. So this is an effort that is very holistic, very connected. And we are trying to filter out those things that work best and accelerate them.

Question: I found your discussion of initiatives very interesting, but initiatives are kind of hard to do, and I wonder if maybe you have some suggestions as to how you would implement them. How would you efficiently implement the initiatives you were talking about?

Kalil: It is important to indicate from the very beginning that some initiative goals are going to take a long time. When President Clinton gave a speech on nanotechnology at California Institute of Technology, he was very careful to say some of the goals of the NNI might take 20 years to achieve, which is why there is an appropriate role for the federal government. In terms of structuring these, it is important to have a portfolio approach where there are some near-term deliverables, but also longer-term challenges that are going to require sustained support for fundamental science and engineering.

Question: I think it is all well and good to get our young K–12 students excited about science, but I feel that when they reach the university system, the university system is failing them. I would like your remarks about how we might be able to incorporate more professional development for future teachers at the beginning of the degree program instead of at the end.

Alberts: This gives me a chance to talk about a program that I think provides a very good model. The University of Texas at Austin has a program called "U-Teach." It is run by their Division of Natural Sciences to attract and prepare science and mathematics majors for K–12 teaching careers. They give incentives to entering students by giving them free credits. All the science and math majors can take a first-year course for about four hours a week that takes them into the schools to see what science teaching is like, working with some of the best teachers in the area. This gets them familiar with what it is like to be a science or math teacher before they actually commit to their major and their plans. U-Teach is a four-year program that produces about 100 science and math teachers a year. The courses were designed not only by the professors, but also by some of the best K–12 teachers in the area, who helped with the curriculum for several years.

You could think about this kind of program in many other areas. You could bring in professionals to try to design a program that would, very early in the college years, acquaint interested students with that profession. As said earlier, half of the people who get education degrees decide by the time they get their degree that they do not want to teach. This is a crazy waste of resources. Generating a closer connection at universities with professionals would make a lot of sense, enabling students to make career decisions early so that they can make the appropriate investments in their own education.

Question: One of the things I have found though is that, especially being a non-traditional student coming from business into science, there is an overwhelming mindset amongst research universities that the professors are training future professors, not scientists.

Alberts: Well I am sorry to say that the Academy has obviously failed. We have been working on this issue for about eight years. We produced a booklet called *Careers in Science and Engineering: A Student Planning Guide to Grad School and Beyond*. After it was published, I was invited to many graduate student symposia where the graduate students told me, "Well the problem is that I want to do this or that using my science degree, but I don't dare tell my professor because the professor will disown me and won't pay any more attention to my work." So then we produced a second booklet called *Adviser, Teacher, Role Model, Friend: On Being a Mentor to Students in Science and Engineering*. Knowing that professors would never read it on the Web, we suggest that the students buy it and put it on a professor's chair in the middle of the night. Obviously not enough people have been doing that; so we should sell some more books!

Bordogna: NSF has two criteria that all proposals have to be reviewed against, and one of them of course is, what is the intellectual value of all this? And the other one is what the greater impact of it is? And that greater impact has many little ticks under it that you can do. You can concentrate on diversity; you can produce some infrastructure that might be useful across the nation. One has to do with getting into the kind of thing you are talking about. There are many things you can have a greater impact on. One is to have a greater impact on a student's career by being more professional and so on. So there are ways for professors to write proposals and get money to do some of these things.

Moore: The problem you have is a huge one. There are still many faculty members who believe that their only job is to make more faculty members, and they should practice birth control. You can train one to replace yourself and that is it.

Bordogna: Malcom mentioned it this morning as one of the things that is sort of torquing the system. You have to integrate research and education, and you have to do a lot of things we are talking about to get this award. That program is not just focusing on the single investigator in research. What it is creating is a faculty member for 21st century academe who is kind of the person you talking about here.

Question: Duncan Moore, given the statistics you have, especially in the physical sciences, would it be almost impossible to absorb any significant increases in research development given the state of the population? And second, won't the recent reported increases in tuition across the country exaggerate that?

Moore: The second one first. Probably, but I am not sure it is going to hurt science anymore disproportionately than any other field. I think it is going to hurt all fields. When I looked at one of Jack's view graphs this morning on the Apollo program, at least 50 percent of the people in this room got excited about science during that period because students follow the money. If there is a lot of excitement over a program, students will move into it. So the question I thought about asking Jack was: “Is there any way short of having some huge program, like Apollo, that will actually get a lot of students to go into the field?” If we continue along the 10 percent solution, will we just keep going that way with no way out?

INTERNATIONAL COOPERATION

INTERNATIONAL COOPERATION

Norman P. Neureiter

Let me start with a few words of appreciation to some special people. Neal Lane, your recommendation and support had a lot to do with my being selected by Secretary Madeleine Albright as her Science and Technology Advisor. It was the first such position in the history of the State Department. It has been a great job and has certainly kept me off the streets and out of my wife's garden for the last three years. It is always exciting to be the first at anything—there is no benchmark to measure yourself against. But it was also a job where literally every day there was some new issue, new contact, new challenge, or new opportunity to deal with. It was sometimes frustrating—the caprice of government decision making (also known in my office as the one-issue weenie effect) can at times really get to you. But it was never boring; I just loved the job.

On my final interview for it just two months before the 2000 election, after a brief chat with Secretary Albright, it was apparent that I had the job. Her Chief of Staff finished up the interview by saying, "By the way, don't sell your house in Dallas, you could be out of here in three months." I looked at her, put my hand on her arm and said, "Lady, I don't need this job, and my wife does not want me to take it, but if you offer it to me I cannot resist. I've been in training for this for 40 years."

Jack Gibbons, I must also thank you. You were acting as a part-time adviser at the State Department after leaving the White House, and you warned me that I was about to enter the most technophobic culture that you had ever seen. But also, even before I was appointed, you invited me to give a speech to a National Academy of Engineering (NAE) symposium on Earth Systems Engineering. It happened to come on my 35th day on the job, and I titled the speech "It's the World, Stupid."

I stole that title from *New York Times* columnist William Safire and was trying to make the point that, in a world of inordinate disorder, America remained the only credible bearer of the mantle of global leadership; and yet, how sad it was that the election campaign of that year was essentially devoid of any mention of foreign policy, despite Jim Lehrer's valiant efforts during one of the debates to raise such issues. I still think my comments in that talk were right on target, and when I opened the *Washington Post* last Sunday (October 26, 2003) to an article in the Outlook section with the headline, “This Election Has Foreign Affairs Written All Over It,” I realized how much things have changed in America in the last three years. Foreign policy is very much at the top of America’s agenda today.

Jack Gibbons also gave me an introduction to a key audience of supporters at the National Academies. The support for our work at State from those institutions under Bruce Alberts (National Academy of Sciences), Bill Wulf (National Academy of Engineering), Ken Shine (former president of the Institute of Medicine) and Harvey Fineberg (current president of the Institute of Medicine), has remained steadfast and rock solid up to this day. The attitude was contagious and we obtained tremendous interest and support from AAAS, many professional societies, the university science and engineering communities, and from the technical agencies of the U.S. government. In other words, the outreach process to the science and technology community has been in great shape.

Jack Marburger, I also need to thank you and your staff at OSTP for the terrific cooperation that you gave our office. Clearly, with its overall role in science and technology policy and with you as director, in effect serving as the “Science and Technology Minister” for the United States, OSTP’s sustained support must be an essential part of whatever we try to do at State in the area of science and technology.

Our basic mission was derived from the National Research Council’s (NRC) seminal study in 1999 of science and technology and foreign policy. That mission was to strengthen the State Department’s capacity to fully integrate science and technology considerations into the formation of U.S. foreign policy. I would like to be able to say that you can do this by whispering in the Secretary’s ear, but nothing could be further from the truth.

So I decided if we were going to penetrate to the heart of Jack Gibbon’s “land of technophobia,” we needed more scientists in the system than our three-person office could ever have. We focused on getting more scientists through expansion of fellowship programs. The greatest increase was in the AAAS program, but The American Institute of Physics (AIP) and Institute of Electrical and Electronics Engineers (IEEE) are also providing science fellows to State, and the American Chemical Society (ACS) and Industrial Research Institute (IRI) will have fellows in the future. In the fall of 2003, we had a total of 40 Ph.D. scientists and graduate engineers in the building, spread among 16 different bureaus, including five of the six geographic or regional bureaus that are the absolute epicenter of the department, where that "technophobic" heart beats the strongest.

My successor, George Atkinson, is putting the final touches on a new Jefferson Science Fellows program that he has worked out with funding from private foundations and universities, which will add more fellows by next fall. We have also put a new focus on getting science students into our summer intern program, and we have gotten more scientists into State from other agencies. A special program, in which NSF was the first participant, is placing over 30 scientists a year from technical agencies of the government into tailored, one- to three-month assignments at U.S. embassies overseas. I happen to think that is a terrific program, because the ambassador can readily see the benefit to the embassy of having more contact and interchange with the leaders of the host country's science and technology community.

The reason that fellows are so important is that they represent distributed wisdom around the building. The State Department is a complex institution of 26 bureaus, six of them geographic bureaus covering all the regions and some 191 countries of the world. These bureaus oversee more than 250 embassies and consulates staffed by Foreign Service officers that Secretary Powell calls the front line of national security. The other bureaus are known as functional bureaus and they focus on specific missions such as arms control; non-proliferation; oceans, environment and science; consular affairs; educational and cultural affairs; administration; political/military affairs, etc. Rarely do purely scientific issues go to the Secretary of State. Big political issues go there, such as North Korea, the global HIV/AIDS epidemic, the Iranian nuclear issue, and Iraq reconstruction. Often, different bureaus have very different views on the policy issue at hand. And quite often, science and technology is an element that must be considered in those big issues. That was a salient point in the NRC study. However, if the science and technology considerations are not included at the bureau or office level as the policy documents move up through the system, the chances of affecting the policy at the end are not good. That is why it is essential to have the science fellows at the working level inside the bureaus.

For the first time this fall we have a senior physics professor working as a fellow on International Traffic in Arms Regulations (ITAR) export control issues in the Political/Military Affairs Bureau. The staff calls him "Doc." This area has been a huge source of difficulty for universities that have space research programs with foreign students or foreign cooperators, particularly if the projects include building satellites with a company contractor.

It is the "deemed export" issue. Our office worked on this issue with NASA for nearly two years. Although the interagency process finally produced a new set of regulations, they still are not very satisfactory for the universities. Hopefully, our AIP science fellow can make some constructive contributions in this area.

So now you have heard about two aspects of our program at State—the outreach and the fellows. They are in good shape. The third element in our program was to select some specific science and technology initiatives that, in my judgment, could demonstrate the direct value of science and technology for achieving of certain political objectives with other countries. It was a kind of consciousness-raising exercise to demonstrate to the Foreign Service people the potential value of science and technology as an active instrument of foreign policy.

Just before mentioning an example or two of that, let me just say a word about the world we were facing. I spent nearly thirty years in two large corporations, one in petroleum and one in electronics. The big corporate world has heartily embraced globalization. Mergers and alliances, especially in high tech industries, are de rigueur today. Exxon and Mobil were not big enough alone to address the global marketplace, so now my $83-per-month Exxon retirement check comes from the Exxon Mobil Corporation. HP and Compaq were either too big to have to compete with each other or not big enough to compete in global markets, so they merged. That was not without a lot of fuss, but nonetheless, they did bring it off.

But the political world has not bought into this. There, centrifugal forces prevail. Ethnic tensions, nationalist ambitions, and economic disparities continue to divide the world's peoples at a remarkable rate. As corporate industries get bigger and bigger, political entities get smaller and smaller. This is why we have today almost 200 countries in the world. The processes of division or separation can be peaceful and democratic, but increasingly they are not. They are violent and fueled by passionate convictions that emerge as terrorism or suicidal attacks. The point is, the political world is very different from the business world, and business solutions and market solutions do not provide complete answers. We are all struggling to find the right answers to these questions and, in doing so, to protect our own country and our own citizens. The world community faces two great challenges today: globalization and global terrorism.

So what were the scientific projects that struck me as having political value for the regional bureaus or country desks? One was the formation and implementation of the Indo-U.S. Science and Technology Forum. This grew out of two high-level dialogues with the Indian science community that was begun by Neal Lane; and establishing the Forum became a major objective of U.S. Ambassador to India, Richard Celeste. Although a modest rupee endowment had been provided and an agreed framework set up, nothing had happened. The U.S. administration changed, all the presumed board members left on January 19th, and the money was about to be lost. With strong support from the South Asia Bureau and the embassy, I stepped in and set up a somewhat lower-level U.S. board and arranged a first meeting with the Indian counterparts. For three years now I have served as co-chairman of the Forum, with strong secretarial support from the National Academy. In this way, we have sustained a formal mechanism for bilateral science and technology cooperation with India.

This happens to fit very well with present U.S. policy toward India, which stresses cooperation, encourages their economic and scientific development, and has relaxed some of the sanctions imposed on India after their nuclear tests. The Indians, particularly, want more cooperation in nuclear power, civil space activity, and easing of export controls on high technology items. In the bureaucratic world, this is now called the “trinity of issues.” Some relaxation continues, but proliferation concerns and, to a lesser extent, intellectual property concerns still limit the relationship. On the other hand, the Forum is working and is considered a meaningful part of the new and much warmer relationship of the United States with India.

When President Bush met with Pakistan’s President Pervez Musharraf in Washington almost two years ago, in addition to arrangements to fight terrorism and to provide U.S. assistance in education and economic development, the two leaders also expressed a desire to develop science and technology cooperation. This was of great interest to our embassy and to the Pakistan desk. When no one else picked this up in the U.S. government, our office did. Working with Pakistan’s very impressive Minister for Science and Technology, Atta-ur-Rahman, we laid out a framework for a cooperative program. After a year of repeated requests, the Agency for International Development (AID) finally agreed to provide $2 million to implement this program. The Pakistanis put in half a million, and when I went to Islamabad for a visit, they raised their share to $1 million.

On that same visit, the U.S. Ambassador and I were received by President Musharraf and spent nearly 40 minutes with him talking about what a greater scientific relationship with the United States would mean to the economic development and the future of Pakistan. Well, all of this took place more than four months ago and still nothing has happened. Even though we had a Science and Technology Agreement signed and money was committed by AID to run this program, the money has been blocked by a single staff member in the Congress. There is nothing wrong with the program; he likes the program. It is because State should not be spending "assistance funds," but using Economic Support Funds (ESF). That sounds like pure bureaucratese, but it is an important issue to someone. In the meantime, there is no money, no program, high embarrassment on the American side, and negative political impact.

There may be a chance to find some ESF money when there is a 2004 appropriation and, of course, we have not given up, but it is a bit depressing. More graciously put, this incident reflects the caprice of government decision making. The point is that nothing is done in government until it is really done—until the money is in hand. In fact, I am continuing to work on these issues in my new role as a part-time consultant to the State Department. And you can see why there is plenty of work. (Note added during editing: Things did finally work out. The money was provided and an science and technology cooperative program with Pakistan is now underway.)

I am not going to go through in detail any other examples of science and technology for political purposes, but Vietnam was one area where we had some success. We did some things with Brazil that were really appreciated by the political folks. We led some initiatives with Russia and Japan. And we worked with the Arab Science and Technology Foundation in the United Arab Emirates (UAE) in a new effort to engage with the Islamic world.

But let me give one more example. I rode the coattails of Jack Marburger and Ray Orbach, the director of the Office of Science in the Department of Energy in the successful effort to get the United States to rejoin the International Thermonuclear Experimental Reactor (ITER) consortium to build an experimental thermonuclear reactor, a critical way station on the road to fusion energy. China and South Korea have also joined with Japan, the European Union, and Russia, though Canada is a little uncertain today. The consortium is currently at a very critical stage in the decision process on the siting and cost sharing. To me this is an extremely important test case for the viability of big multinational science and technology projects. Can five nations and one region come together and work for ten years to build the reactor and then continue to cooperate in its operation for an additional 10 to 20 years? Can and will each entity compromise its own domestic fusion program, its domestic industry involvement, and agree to sustain funding for work at a site thousands of miles from home? Can the export control issues and the intellectual property rights issues all be resolved in time to make this thing really happen in the coming year? ITER has been on going for 18 years. We are approaching a time when firm decisions must be made or it could founder for good. That would be a great disappointment, at least to me personally and I think an enormous disappointment for a very large community around the world. It would imply a dim future for big science and technology cooperation. It would also have unfortunate implications for the next generation particle accelerator, which is of course still a few years away.

I have to confess something. I am an inveterate engager in science relationships with other countries. We are all prisoners of our own experience, and my experience is in Poland and Eastern Europe where, during the Cold War, we actively sought to keep channels open to the scientific communities. We knew many people agreed with us and did not like their own governments. We did the same thing in the Soviet Union via the Pugwash Conferences, the National Academy's Committee on International Security and Arms Control (CISAC), and a Science and Technology Agreement that was negotiated with the Russians at my dining room table in Bethesda in 1972 prior to the Nixon-Brezhnev summit. Those engagements of our science communities in the 1960s and 1970s were in my view very instrumental in eventually achieving the Test Ban Treaty and other arms control agreements. All of these elements were pieces of the process of finding ways to keep us from killing each other. Many Americans, in fact, do not believe very much in these kinds of engagements for fear that we might give too much away and are in some way helping the enemy. Admittedly, it is a trade-off, and the world is not as bipolar today as it was then. People did not want to have contacts with the Russians or the Poles in those days. But the truth is that it was always the Soviets who did not want their people to have contacts with us; it was the Eastern European governments, particularly the Czechs and Hungarians (also in my area of responsibility), that wanted to keep us away from their scientific communities.

This coming week I am speaking at a major meeting on U.S.-China relations at Texas A&M. It is perhaps not well known, but when Henry Kissinger went to Beijing in 1972 to arrange President Nixon's trip, he carried with him a collection of 40 possible cooperative science and technology projects. These were eventually laid before the Chinese as evidence that a tangible, cooperative science and technology program could also emerge from the new political relationship that was being proposed.

Those 40 projects were cobbled together by me in great secrecy under Ed David's leadership (a former Science Advisor to President Nixon, who could not be with us today) with the help of a great group from Office of Science and Technology (OST) and the Committee on Scholarly Communication with the PRC at the NAS. We had about ten days to do it in, and the last three days and nights were more or less continuous, but we did get them done. Those proposals ultimately became the basis for actual exchanges and projects administered by the Academy until the signing of an intergovernmental agreement that was put together by Frank Press, the Science Advisor during the Carter administration. That relationship has evolved into the quite incredible range of cooperative programs that we have today with China, including somewhere between 60,000 and 70,000 students that are in U.S. universities—at least two-thirds of them in science and technology fields.

Bruce Alberts just came back from China and told me about the activity and energy he saw there. In his last speech in China he talked about science education to an audience of 3,000. The president of China sat through much of the talk, reflecting the high priority that China accords science and technology and the way the Chinese are surging forward.

I am keynoting the science session at this U.S-China conference at the Bush Library at Texas A&M, where Henry Kissinger and former President Bush will be the lead speakers. I have seen the draft speech of my Chinese counterpart for that session, and she is going to make two important points: to express concern about the inadequate funding mechanisms on the U.S. side for international science and technology cooperation and also to express a desire for some kind of forum, which I suspect may be the idea of a U.S.-China bi-national foundation for science and technology cooperation. We will see what comes from that discussion.

Again, to draw a parallel with the Russian experience, this kind of close relationship in China, while I think it offers us a hopeful image of the future world, is not popular with everyone in the United States. Some people say that we are helping them to become stronger and that these science and technology smarts can be applied to strengthen China militarily with long-term negative implications for challenging the United States around the world.

These relationships interestingly have been remarkably stable despite four or five major adverse events. There was, of course, the Tiananmen incident, which pretty much closed things down for a couple of years, but the science relationship went on. Then there was the accidental bombing of the Chinese embassy in Belgrade. My son was working in our embassy in China at that time. That is when they burned one of our consulates and demonstrators threw rocks through my son's embassy window. When the U.S. spy plane landed on Hainan, the Chinese had their people under better control. We also have the occasional saber rattling over Taiwan, and then the Cox Report (1999) where two major U.S. aerospace companies were accused of transferring missile technology to the Chinese. The cooperative science activities have continued despite these perturbations in the overall relationship. After 9/11 the plusses and minuses in this relationship have gotten more complicated than they were before; however it does appear that the Chinese also appreciate the importance of joining us in the global battle against terrorism.

This post-9/11 world that we are in today has raised another issue that I consider one of the most serious barriers to our international science and technology cooperation. It is the visa problem and it has resulted from legislation that was passed in response to the 9/11 catastrophe. But let me put this issue in an even broader context.

The military strength of the United States is our hard power. Today, no one in the world can challenge that hard power on the battlefield. There is also another side to America, our soft power—sometimes called our co-opting power, as Joseph Nye, dean of the John F. Kennedy School of Government at Harvard, has called it. It is the siren song of human rights, of an open society, of freedom of inquiry, of speech, of religion, all the elements of democracy. Our science and technology, our universities and the relationships we build around the world are the instruments of that soft power.

But what message do our visa policies send? Well they might be saying "thank you" for sending 50 percent or more of our physical science and engineering graduate students to the United States over the last few years; "thanks" for sending 200,000 high-tech workers a year under the H-1(b) visa program; "thanks" for sending your postdocs to do research at NIH (there are 1,600 of them from overseas who come to work on diseases that afflict Americans); "thanks" for sending people to staff the physics and chemistry labs at our universities. But now if you are from China, Russia, Eastern Europe, or from a Muslim country and you are a scientist and want to study or work in the United States, it is as if we are saying we do not want you. The chances of your getting here are not what they used to be.

I am sure you all have some horror stories of missed meetings, of fellowships not accepted, of some of the best and brightest going elsewhere. No one can approve a visa for a scientist from any of these countries except a Washington interagency committee, not the ambassador to the country in question, or even Secretary Powell. So we tell everyone to apply three months ahead of time, but not everyone can do it, not everyone wants to do it, and not everyone knows about the invitation that far ahead, and so, often, things do not work. Some of those people go to France, Australia, the United Kingdom, Germany, or Japan. Those countries are very happy to take the best and the brightest of those who really wanted to work in the United States.

Now, I know that visa processing has improved somewhat. There has been progress and we keep working on the issue. But I truly believe we are depriving ourselves of one of our greatest active foreign policy instruments in the way we are presently managing our visa policies. We are muting the soft power message of these great United States, a nation whose very essence rests on the principle of openness. Remember that Cold War movie, *The Russians Are Coming*? Well there was an op-ed piece by the Russian Ambassador, Yuri Ushakov, in the *Washington Post* this year that was titled, "The Russians Are Not Coming." It was about the visa problem.

Because I am an engager, I hail the efforts of the National Academy of Science (NAS), with little or no support from the U.S. Government, to bravely carry on its program of interaction with the Iranian Academy of Sciences. They still have a series of workshops coming up that, because of visa problems, will be held outside the United States. I still believe interaction with like-minded groups in those countries is of value to us. I cannot help but believe that the engagements we carried on with the Soviet Union and Eastern Europe were important elements in the final collapse of those regimes. By the way, I once said this to an acquaintance that had worked for the CIA. His forceful response was: "Are you kidding? I brought down the Soviet Union. Every piece of military equipment that went to the Mujaheddin in Afghanistan went over my desk. That's what brought the Soviet Union to its knees." I have not seen him for many years; he has long since retired. As you know, success has many parents.

The point is that I see our international science cooperation in a political context. In addition to the above examples, it is also clearly one of our most powerful instruments for helping the developing world to begin to build an indigenous technical capacity for linking to the global economy—an economy that is driven by technology. That is why the new study that the National Academy of Sciences/National Research Council (NAS/NRC) is just now beginning on the role of science in the United States Agency of International Development (USAID) is so important. It could have a very significant impact in getting more science and technology into the USAID system. Despite a series of fits and starts over the years to make science and technology an identifiable and pervasive part of USAID's activities, it still is not, even though many of its projects are fundamentally technology based.

It should be pretty obvious that I really believe in this whole area and I hope somehow to stay involved in these issues, even in my retirement. I strongly believe in using our great strengths in science and technology as active instruments for building better relations around the world.

The potential benefits from science and technology cooperation are very great. We want to address common problems of the modern world in fields such as energy, protection of the environment, infectious diseases, etc. We want to draw on the best and brightest from around the world for the benefit of science and increasing the store of human knowledge. We want them to be able to work in our facilities, which are often the best in the world. We want to apply our science and technology skills to the challenges of sustainable development and to narrow the gap between the developed and developing worlds. We also want to use science as a carrier of American values of freedom of inquiry and entrepreneurship and to build strands of stability into the fabric of our relations with other countries, in short, as an instrument of soft power. And we want to build ties to the intellectual and scientific communities of other countries, even where there may be severe political disagreements between the governments.

But we still face some barriers. I have already mentioned the visa problem and the export control problems and alluded to the nonproliferation concerns that prevent us from discussing nuclear safety issues with India. Nonproliferation is a very dominant issue in U.S. foreign policy today and represented by a very strong bureau in the State Department.

Another problem is that, in general, science and technology issues tend to be marginalized in the diplomatic community. Certainly the NAS/NRC study and resulting creation of my job at State were attempts to change this situation and bring science and technology issues to the fore. But this is a long-term process and continued support of the science community is essential.

The increasing importance of intellectual property rights related to research can also limit cooperation, especially as universities continue to emphasize patents and their own licensing activities.

Linkage of cooperative science and technology agreements to progress on other issues has also been a problem, particularly in our relationships with Russia. Even in the darkest days of the Cold War, we were able to maintain our cooperation in high-energy physics with Soviet scientists. While we recently got agreement to proceed on a new cooperative protocol, for the past five years several programs have been stopped because approval was linked in U.S. policy to demonstrated progress on other issues in unrelated areas.

Finally, a major problem lies in the funding for international cooperation. There are no dedicated funds for this area in most agencies of the federal government. Furthermore, legislation governing science and technology funding generally requires agencies either to justify their international work in terms of their benefits to US science or to their domestic missions. Ironically, the most liberal rules are in the department that, in general, is most opposed to these interactions—the Defense Department. Almost anything can be funded abroad if it is done on behalf of national security.

Does one need new legislation appropriating money for science and technology cooperation? That is one possibility and to some extent it has already happened. When the Soviet empire imploded, Congress passed the Support for Eastern European Democracy Act and the Freedom Support Act to assist the transition in Eastern Europe and the countries of the former Soviet Union. Some of that money did go for cooperative science programs with those countries.

But, the same goal could be reached simply with changes in the nature of the spending authority for each of the technical agencies. It would take a resounding authorizing policy statement by the Congress. It would have to say that science and technology cooperation is an active element of U.S. foreign policy, and that each agency is charged with defining that policy in terms of its mission and with the political guidance of the State Department to ensure overall compatibility with U.S. foreign policy goals.

I recently learned that there was an effort back in the Carter administration to create a new government agency for the direct support of international cooperation in science. The proposal had actually made it through three of the four congressional hurdles—two authorization bills and one appropriations bill in the House—but it was killed in the Senate by one member who felt it would tread on the toes of AID. What a shame!

In truth, I am not sure another agency is the best answer to the problem. America's science and technology cooperation needs to be broad and encompass the full range of mission-oriented research of our federal technical agencies. It would require an indication from the Congress that international science and technology cooperation is, in fact, encouraged and fundable. I was pleased to see in the OSTP/OMB budget guidance to the agencies this year a brief mention of international cooperation. One of the six criteria mentioned for gaining favorable consideration for funding was if the project "strengthened international partnerships that foster advancement of scientific frontiers." Administration of money is not simple, but I strongly believe that it is a problem we need to solve.

By the way, we did sell our house in Dallas and bought one in Washington. I survived the transition to a new administration and I have worked with great enthusiasm for Secretary Colin Powell since January 2001. He has been a strong supporter of what we are trying to do; he spoke eloquently about science and the State Department at an annual meeting of the National Academy and recently reaffirmed his commitment to science and technology by approving George Atkinson as my successor as his Science and Technology Advisor. Still, for all of that, and while we have in fact made progress these past three years, I want you to know that science and technology is still shallow-rooted in the State Department as an institution, and there is much more to do. For all of you who share my view that science and technology is an essential element of foreign policy, eternal vigilance should remain your watchword.

INTERNATIONAL COOPERATION PANEL

Mildred Dresselhaus

I will cover five points on what I was asked to talk about: international collaboration. When you are on the last segment of the conference, many of the topics have already been mentioned. Bridging the gap is the topic, and I would like to talk first about how scientists bridge the gap to society, and give you one example that I found out about very vividly when I was serving in the government. I call it convening power. When I was serving in the Office of Science at the Department of Energy, the Secretary asked me several times to do something for him in foreign countries, and I made use of the fact that I was a scientist to carry out my assignments. Science is worldwide. Practicing science is known by all other scientists around the world. When we show up in a foreign country, we even get welcomed, and we have a confidence level that starts out on line one. That was really quite amazing because I knew people that the embassy folks did not know. I had the connections to do my job in some cases better than they had. That was really quite an eye-opener for me. Some of the other speakers before me mentioned how the scientists played a large role in bringing down the Berlin Wall eventually because, behind the scenes, they had been talking together for years. During the time we were working together at the APS, I was sent over to China in 1983 to negotiate an arrangement to help the Chinese overcome a period of ten years where very few of their scientists had training to assume university positions because of the Cultural Revolution. We were going to help them by bringing some people over to the United States and give them training. I was over there for another reason. I was there to help them set up material science labs in their key institutions around the country. I used that entry point to negotiate with them about this exchange with the scholars from China whereby both countries would benefit. That was the idea—how we could both benefit. And we did both benefit handsomely from that exchange.

I would now like make the second point, which has to do with bridging the gap, but it is the reciprocal of what I said before. This is how science in the United States benefits from the international scene. As you know, scientific advances are not all made in the United States. We need to capitalize not only on what happens here but also on what happens everywhere. When I was serving the government, I made use of one study that

I had some involvement with through my work at the Academy, and this was the Ralph Gomory study, the so-called Goals Report, that says that the United States should have a leadership position in all fields of science that are important enough for us to think that we should be leaders, and we should be among the leaders in other fields that may be of secondary importance to our national goals. This very simple idea, I found, was something that government folks could resonate with. I used this as an argument to tell me how much science was appropriate for the Office of Science, and in appropriate cases, I could easily rationalize that we were not doing enough and I could get people on the Hill and elsewhere to agree with that. So this was the case where we were using the feelings of people out there on the Hill, who might love science. People in government like to hear about exciting science, and they are always welcoming us to tell them about it. As they said, they had free MIT courses for me when I came to visit. We should capitalize on these relations in bridging the gap in cases where the science community and the public both benefit at the same time.

The third topic I wanted to say something about was promoting scientific exchange. In his article in *Physics Today*, Neal Lane talks about Ben Franklin; he says many nice things about him. But one thing he says is that, "He'd also realize that the general public must know why it is essential to maintain freedom, openness, and international cooperation in science and, in particular, why discouraging women and men from coming to America to study science is so damaging to this nation's future."

You have heard already today about the need for free exchange of scientists to come, for example, to attend conferences that are held in this country because, when conferences are held in this country, most of the participants are from the United States and we benefit from our visitors, so we should do what we can to keep those doors open. We heard about students and how they are having trouble after they get admitted to our universities in the United States. They have trouble getting their visas to come to the United States. But what I did not hear yet anything about was the importance of having our young people go abroad and study in foreign institutions. I was an exchange student myself, and I thought that was a beneficial experience on both sides. We need more young Americans to go abroad and learn from others, and learn about their cultures. It really helps us do science better in this country. The United States has some very nice collaborative programs that make it possible for graduate students and postdocs to go for short periods abroad in the form of bilateral exchanges from NSF (I have one of those from South America right now, and it is an excellent program.) It is not a lot of money—it only provides for transportation—but it opens so many doors. It is amazing.

The fourth topic I would like to talk about is the large facilities. We have already heard something about that. We heard about the International Thermonuclear Experimental Reactor (ITER) from Norman Neureiter and the importance of that. I wanted to say that, during my watch, when I was working for the Department of Energy, I benefited from the excellent open policy that our national labs have in welcoming people from other countries to use our facilities. We had many visitors coming from everywhere to use our synchrotron facilities, our high energy physics facilities, and so forth. It is not going to be possible in the future for the United States to have facilities in all fields. ITER is one good example. If plasma physicists are going to be at the cutting edge, they have to be involved in some international collaborative program because there will not be money available to fund a $5-billion program like ITER in the United States. So if our scientists want work with burning plasma physics, that is the way it will have to go. I think that our scientists are accepting that concept and working nicely along with making that happen. And now, of course, the political side of it has to be worked out, and we hope that that will happen. In the high-energy physics field, we are in a very unusual situation. The focus of the best facilities is now in the United States, and in foreign countries right now they are in the building phase, so they have to come here to use our facilities. This gives us a strategic advantage during these years now for us to build up good will so when the time comes and our scientists have to go abroad because the best facilities are elsewhere, then they will be able to enjoy the same nice advantages that we offer to visitors in the United States.

U.S. scientists, for many years, have had very strong collaborations with scientists worldwide; this has continued for a long time. Right now we are in a different situation, the European Union (EU) has its own enclave of treaties and arrangements and the United States has not been included in this. This is some problem for U.S. scientists because they are not involved in EU programs, and it is also some problem for the Europeans because they like working with us, but there is not a good mechanism to do so. We hope that this can be changed and U.S. scientists can also join on these ventures. Secretary Spencer Abraham spoke recently at a European conference on hydrogen and the statement that he made was that it was important for people to work together; this is including the United States, and for people abroad in other countries to leverage scarce resources and advance the schedule in research and development and in demonstration in the hydrogen economy. As you know, Secretary Abraham was very interested in that problem. The problem is very difficult and for anybody to have success, we have to take advantage of advances whenever they are made and in whatever country they happen to be made. It is my hope that statements like that and perhaps some backing behind them may lead to a whole new era for international collaboration in the area of small science, where grants—joint grants as Europeans enjoy under the EU—will also be accessible to people from other countries like the United States to join in these interactions and collaborations.

INTERNATIONAL COOPERATION PANEL

Houston "Terry" Hawkins

I am excited to be in the fair city of Houston possibly because my first name is Houston. Being here for the first time is quite a happening for me. But my wife has used that name, Houston, many times. When she is angry with me, she calls me Houston; when she is happy with me, she calls me Terry. Well, yesterday was a Houston morning. I got up, after rushing into city the night before to come to this conference and my wife walked over to the closet and said, “Houston we have a problem.” I said, “What is that problem?” She responded, “You don’t have any pants.” In my haste, even though I am a former intelligence officer, I had packed my suit coats but not my suit pants and so I thought, “What am I going to do about this horrible situation?” Frankly I was so terrorized at that point that a new definition of terrorism came to mind: Terrorism is showing up at a conference without having any pants.

I called a lot of my friends in the CIA, explained that I had this problem. They said, “That’s no problem. We will run the dress code through the interagency process and by the time we are finished you will not be able to tell the difference between a pair of pants and a pair of boxer shorts.” And I said, “Well I don’t have the time to wait on that process.” So I immediately called a friend of mine in the Justice Department and again explained my problem about not having a pair of pants for this auspicious occasion. My friend at the Justice Department said, “Not to worry, we will pass a law that requires everyone to keep their eyes shut.” Well I realized that the process of legislation is a contentious and laborious process, so it takes a long time to get a piece of legislation passed…so that was not any good either. So I called a friend of mine in the Department of Homeland Security and I told her my problem of being terrorized by not having a pair of pants and she said, “As it turns out, we’re developing a sensor that will scan luggage going through the airport and the passengers as well, and this system is capable of telling for certain if there is at least one pair of pants and one coat for every passenger.” But then I realized that this development was going to take some time, and that it was going to solve yesterday’s problem and not today’s problem.

I called friends of mine in the Department of Energy looking for a solution to this horrible problem, and they said, “You are not authorized to wear pants.” I said, “Why am I not authorized to wear pants?” And they said, “Your zipper training is not up to date, and that more people have been hurt with zippers than with plutonium.” So I was in a quandary. The Department of Energy would not allow me to wear pants until I became certified in zipper training. But fortunately, when all else fails, there is always a national lab. For example, I knew people would be back in Los Alamos working on the weekend—because they always work on weekends—so I called them and said,“This is the problem I have: I don’t have any pants to wear to this briefing.” And they said, “Well we’ve got a solution. You send a couple million dollars out here, and we will create a pair of virtual pants that you can ship on the Internet.” I promised to make it one of missions in life to beg the people that have the authority to fund the development of virtual clothing so we can solve future problems like this.

In satire much truth resides. But seriously, when you look at terrorism today, it is no laughing matter. It is a serious threat that we have to deal with, and how we deal with it certainly involves applying science and technology. First of all, we have to define who terrorists are and what terrorism is, and that is not an easy legal problem. Usually the terrorist is the person who did not win—the person who wins is seldom called a terrorist. Basically, the fundamental definition of terrorism, as I understand it, is the use of violence directed towards an individual intended to influence an audience outside an immediate sphere of the violence. In that definition, the real victims of the very horrendous attack on the World Trade Center were the people that were watching the events on CNN or Fox News, because those were the people the terrorists were trying to influence. The poor victims in the building were just an apparatus, a convenient way of influencing a larger audience throughout the world who watched this horrific event over and over and over.

Because of the horrific nature of the September 11 attacks, we tend to forget that terrorism is fundamentally a tool of the weak that depends on stealth, secrecy, and sanctuary in order to survive. There is a tendency to put terrorism in the same category as the Third Reich or the Imperial Japan that we fought in World War II. They are not that. They are very weak organizations. In the situation after Pearl Harbor, we were involved in a death struggle for a period of five years against adversaries who were our technical equals and in many cases our technical superiors. This is not the case with terrorist organizations that can best be described as cabals of guys sitting around in caves or coffee houses trying to figure out how to do something sinister and dastardly to influence someone else. This is not an example of a major power, and yet we sometimes play into the game and allow them to be deemed so by our sensationalist news media. Finally, terrorism often hijacks a larger, more established tradition. The Irish Republican Army (IRA), for example, hijacked nationalist aspirations of a lot of good Irishmen. I know many Irishmen in Ulster who have strong aspirations for a united Republic of Ireland, and they were victims of the IRA just as much as the Protestant Unionists of Northern Ireland. I have a friend there, a Catholic civic leader of a small town in Northern Ireland who was mortified when he saw IRA leader Gerry Adams invited to the White House because, he said, "Those people have killed my nationalist friends."

So, as you see in the case of the jihad's terrorists, they are basically trying to hijack the traditions of the Muslim faith and they are trying very hard to achieve this by using various religious mechanisms such as by issuing jihads and so forth. In the real Muslim tradition, there are two kinds of jihads. One is a jihad involving one's own personal struggles to make oneself better, to make the world better, to make ones' family and neighborhood better, and to increase the family wealth and opportunities. This is a struggle we all go through—we are all involved in this jihad. The other kind of jihad, involving violence against someone else, is a structure within the Islamic religion that can only be issued by caliphs, and there are no caliphs left in Islam. So terrorists like bin Laden either declare a jihad themselves or entice some cleric to issue a jihad in the name of Islam, all for the purpose of trying to hijack the ancient religion for their own evil purposes or to use that religious nomenclature to obfuscate their own moral and intellectual inadequacies.

So if we step back and look at what we can do with science and technology to deal with international terrorism, certainly what technology can allow us to do is manage the two dynamics of terrorism: the probability and consequence of terrorism. This is fundamentally what technology can help us do: make terrorist events less probable and of less consequence. Science and technology can allow us to control the larger agenda that the terrorist has set out to dominate and define. We can use technology to educate our society and the people of the world; we can tell our people about the consequences of terrorism in a way that they can understand. Right now in this country, as a result of almost 60 years of anti-nuclear propaganda, we have a society that is afraid of one click of a Geiger counter. That fact has prepared our society to be victims of nuclear terrorism, especially "radiological dispersal devices" or RDD's, which is a significant threat primarily because of our phobia of radiation in any amount. Therefore, what we need to do as technologists and scientists is educate our citizens and tell them about the real consequences of radiological exposure and thereby help undermine and deter terrorism of this nature. That chore will not be easy.

We also need to recruit people in this war against terrorism, regardless of their origins, because fighting terrorism is an international enterprise; anyone willing and able to help should be welcomed. This inclusiveness was our tradition certainly in the 1940s when we were fighting the Third Reich. One of the most amazing aspects about Los Alamos, where I call home, is that in 1943, at a time when we could not brief the vice president of the United States on nuclear technology because of its sensitivity, the secondary language in the cafeteria of Los Alamos was German. We brought the best and brightest we could to solve that very difficult problem. Later, as the Cold War sprang forth, there was a meeting in the Pentagon in the most secret places of secret places. There, four people sat at the table developing the Nuclear Posture Review that would go to the president and form the basis of our nuclear weapons strategy for the next five years. In that meeting, there was Siegfried Hecker, the Los Alamos laboratory director, born in Poland; General John Shalikashvili, also born in Poland; Al Nareth, President of Sandia Corporation, born in East Berlin; and John Nuckles, director of Lawrence Livermore National Laboratory, the only native-born American in this meeting. Now that is what makes America great—that we can take people from all backgrounds and heritages who have a vision of democracy and freedom and who are willing to utilize their genius and muscle in the furtherance of this enterprise. When we take xenophobic steps that deny participation of people willing to work with us, we are going down a dangerous and slippery slope from which there may be no return.

Technology can serve to shape the contest. By modifying the tactics of terrorism, we can make the terrorists behave in ways that make them more vulnerable. I'm afraid this aspect cannot appropriately be discussed in this venue. But technology also can be used and should be used in modeling responses to try to define the legal authorities and administrative strategies we need to respond to terrorism. For example, today if an improvised device or an RDD goes off in New Jersey and we have to collect forensic samples from the explosion and take them back to Los Alamos for analysis, we will violate something like 35 different state and federal laws in taking that debris back there. Yet, we have to get the debris back there promptly if we expect to make any decision as to where that material might have come from. We can model these situations and play them out, and try to find out what kind of legal authorities and what body of laws we need to deal with these situations. More importantly, I know people that work with me that will have to go out and cut the green wire or the red wire if, God forbid, an improvised device shows up somewhere. We need to have in place legislation that encourages and enables a response that provides the highest probability of success. I do not want the responders to be thinking about the Trial Lawyers Association when they make that most important of decisions,

Ultimately, technology and science can work towards making the world a better place by obliterating the conditions of ignorance and hopelessness in which terrorism thrives. Throughout the world, we need to communicate with candor our aspirations to make the world a better and freer place. We need to dialogue with other people to undercut the basic information vacuum and carefully tailored distortions on which terrorism feeds. We can use science and technology to help make that happen.

My job is such that before I go to sleep I always hope that we secured that day that last kilogram of plutonium or highly enriched uranium that some terrorist was trying to acquire. I do not believe that the hope has been in vain. I do not subscribe to the theory that a terrorist use of a nuclear device is not a question of "if" but "when." Nuclear terrorism is an event that must not happen. We have to believe that as a basic premise for going to work each morning, and it must be the lamp that illuminates the darkness. The only thing that is certain is that we are in a race, and one side will win and one side will lose, and we must be on that winning side. There are no other options.

I recall when William Faulkner received the Nobel Prize in literature for *The Sound and the Fury*. He received it by walking up to the podium and stating, "I decline to accept the end of man. It is easy enough to say that man is immortal because he will endure: that when the last ding-dong of doom has clanged and faded from the last worthless rock hanging tideless in the last red and dusty evening, that even then there will be one more sound: that of his puny and exhaustible voice, still talking." Possibly that voice will say, "Hello, I am the president's science advisor, is there anything I can do to make the world a better place?"

INTERNATIONAL COOPERATION PANEL

Frederick Bernthal

I would like to say a word or two now about the subject of international cooperation and, more specifically, some comments on "mega-projects." I am going to talk about two broad categories of international cooperation in science through mega-projects. The first of these I will call "type I" mega-projects, for example like ITER—the "big bucks projects." There is also a second type of international mega-project that I will classify as "big problem mega-projects," which I will define in a moment. Of course there is an entire other category of ongoing long-term international cooperation in science, all of which goes on very nicely without any government intervention. In fact, it suffers when there is much government intervention in what scientists themselves do best: Seeking out other scientists, wherever they may be in the world, and scientist to scientist, working out useful research collaborations that benefit all of us. I will not spend time discussing such activities, because they obviously do very well on their own. Our interest here is primarily the first two categories I mentioned.

What are the factors that drive cooperation in these two categories? This may be obvious, but first of all, we have to start with cost. We do not do these things for political altruism or fun, although it is true—and I have participated in this during my career—that useful political ends can sometimes be achieved through international cooperation in science. Such cooperation can serve as a political icebreaker, as for example, when I led the negotiation of the first U.S./Soviet Agreement for Cooperation in Basic Science. That was a small path along the way to breaking the ice with what was then still the Soviet Union. But usually you would not find yourself in the negotiating room if it were not for the cost of mega-science projects. So it is cost that drives my so-called "type I" category—things with a big price tag.

The "type II" category entails a problem of such great complexity that it demands international participation. Such a problem might also be big bucks, but it is more likely to be a widely distributed kind of expenditure, where hundreds of heads on a problem might be better than one. I am reminded of the human genome project, which, at least when it started, was thought to be that kind of thing—a project that would allow and require the widest possible international participation. As it happened, computers and other events overtook that concept of cooperation, and in the end, the human genome project was dominated by the United States more than most of us initially expected it to be. And as everyone here knows, one individual in particular, who was not a government employee, did much to challenge conventional wisdom and to expedite the involvement of the lead government agency, the National Institutes of Health, in that regard. In any event, my "type II" is meant to encompass projects like this—very complex problems with issues of common concern to mankind. Most notably perhaps, they include the global environmental issues—climate change being a perfect example—and these are often "megaprojects" in more than just dollars, being so in social significance as well.

Now let me talk for a moment about specific cases, focusing on one or two case studies that I have experienced. (As Norman Neureiter correctly observes, we are all prisoners of our own experience). Obviously the International Space Station (ISS) was an interesting case, because it was sold to some significant degree as a science project. I am not sure if any of the people that sat at the table here this morning actually portrayed it as such, but the fact remains that it was characterized originally by some as a science project. And while cost may have been a major factor in the ISS, it was not cost alone that drove that particular international cooperation; there was also strong political motivation behind it. However it all began, right now the issue for the space station is, as you know, continuity and management for survival.

The second particular case I want to touch on is global climate change. Well, what can you say about that—it probably started out primarily as a political issue. Over 20 years ago, Bill Clark, now at Harvard, edited a volume titled *Carbon Dioxide Review* (1982), wherein he and his collaborators at Alvin Weinberg's Institute for Energy Analysis in Oak Ridge pulled together a set of papers to form a seminal volume on the issue of atmospheric CO_2. But the issue really did not leap into political focus, at least in the United States, until the very hot and dry summer of 1988 (which may or may not have had anything to do with climate change!). Such an event is often what it takes for an issue like that to make its debut in the public policy arena. And, of course, now it is a major issue of common concern.

The third case on my list, the human genome, I have already discussed briefly and I will not say much more about it as a case study. I do, however, want to comment on a rather smallish project that we are involved in at Universities Research Association, Inc. (URA), and that I doubt many people in this audience know much about, if indeed you have ever heard of it. I mention it here because it illustrates in microcosm what it is going to take to have the kind of cooperation we need in the future for the real mega-projects, especially the "big bucks" projects. And in that regard, I would be remiss if I did not comment on high energy physics projects, too.

The illustrative project we are involved in at URA is the Pierre Auger Cosmic Ray Observatory in Argentina. Now why do I focus on that? After all, it is not all that big; the project itself, just briefly, is one that was led initially by Jim Cronin, the Nobel Prize-winning physicist from the University of Chicago. Jim recruited some 15 countries to participate in the project, the first half of which is being built now in Argentina. The Pierre Auger Project consists of a large array of ground-based cosmic ray Cerenkov-radiation detectors, along with other detectors to detect cosmic-ray-induced atmospheric fluorescence. The ground array will cover an area roughly the size of the state of Rhode Island when it is finished; indeed, the engineering test phase of the project is already operating.

But even though Auger's total cost is only $50 million, I can tell you that, with 15 countries involved, and no single country (including the United States) being anywhere near a majority stakeholder in dollars invested, this could easily have been a management nightmare if you ever set out to create one. Luckily, we have had an extraordinarily capable project manager, a man named Paul Mantsch from Fermi National Accelerator Laboratory, and thanks to Paul and his team, things have gone surprisingly well. Indeed, it is actually 10 percent under budget at this point.

Nevertheless, Auger embodies all the elements that you worry about in far-flung international cooperation: problems importing materials for the project; dealing with a complex customs operation in the host country, Argentina; getting people in and out of the country; default on obligations from certain countries—in short, everything you can imagine when you get into a very large, expensive international science project. So while this one may not be that big, in my judgment it has been remarkably instructive. By the way, we hope to go on and build the northern array in either Utah or Colorado at some point in the not-too-distant future. But my point is that Auger has much to teach us about the problems we will inevitably confront in much larger mega-science projects.

Finally, let me say something about one of our principal concerns at URA, and that would be the push in the United States to build a next generation electron collider facility. Most of you know that there is a next generation proton collider now being constructed in Europe, and it must be noted here that Neal Lane was absolutely key to the significant U.S. involvement in that project. So within the next five or six years, the energy frontier in particle physics will shift from Fermilab, currently home to the world's highest energy accelerator, to the Large Hadron Collider (LHC) at CERN. Beyond that, however, high-energy physicists are now laying plans for a next generation electron collider, a more powerful successor to the existing Stanford Linear Accelerator (SLAC). Aside from the question about where this machine might ultimately be built, inevitably one's thoughts turn to cost—in this case perhaps $7 or $8 billion, so it is fair to say it is not likely to be funded entirely by the United States. It is too early to say how much any single country might contribute, and that leads to the issue of how to apportion cost. Should the host country contribute, as has been suggested, 25 percent plus some further share in proportion to its GDP? (For the United States, that would come out to well over 50 percent, a share that I'm not sure is realistic!) Or is there some other appropriate formula, one that takes into account the benefits to the host country and so on? You also get into issues that we have already heard something about here today—visas and the particular problem in the United States of visas and international terrorism. That, in turn, raises the question of how we might tailor things here in the United States, were we to host the facility. Could we persuade our government to create a special "reservation" on U.S. soil, perhaps a UN-type compound, for the purposes of international cooperation in science? How might we do that?

So, there are big issues ahead when it comes to mega-science projects that might be built on U.S. soil (as opposed to ITER, which will not be based in the United States). And then when you get to the practicalities of design of the proposed new collider, there being some grumbling about the United States having already formed a preliminary team to try to determine which of two competing designs might be appropriate. All of these things are illustrative of the complexities involved in pulling off such a major international cooperation.

Finally, I just want to leave everyone here with one thought—some of my friends in particle physics might say a frightening thought. I want to remember with you some lectures that maybe a few of you here were lucky enough to attend 40-odd years ago. I saw them on film as a graduate student at Berkeley, and I still recall vividly those wonderful talks that Richard Feynman delivered at Cornell back in the early 1960s. They were classics, rendered by the superb lecturer that was Feynman. And I particularly want to recall here the closing lecture in the series, where Feynman talked about the prospect that someday the next great experiment would turn out to be just too expensive for anyone to afford. I will not suggest that we are there yet. But clearly, a number of the scientific facilities that one hopes for these days simply must involve the world community because no single country is going to build them, at least not unless any single country sees a prospect for immediate and substantial compensatory economic benefit. (I suspect that the United States would find the money very quickly to do its own ITER if we thought that the demonstration of economical fusion power was just around the corner!)

INTERNATIONAL COOPERATION PANEL

Discussion

Question: I have a question about export control laws. My question is: Is it in the best interests of the United States to not work with other countries' energy production? And the second question would be, what other alternatives do we have?

Neureiter: Back in the Nixon administration when I was in OST—they had not added a "P" to it yet—we spent a lot of time on export control issues. It was an issue then, and I thought, "Gee, when I come back to government 30 years later maybe these issues will be gone." But they are not. Export controls are a big issue again. They are very complicated because the State Department controls the ITAR regulations and the Commerce Department controls the dual-use technology. My guess is that you are talking about a Commerce-controlled item. However the Nonproliferation Bureau of the State Department also has inputs on the dual use items while the Political/Military people handle the military ITAR issues, where they rely principally on the intelligence and defense communities to make the judgments that they then process and put in legal form. These are really tough issues, and the simple impulsive answer to your question is: "No, we ought to be working with other countries because we know we share common energy problems." However, there are laws and they have to be obeyed. Making the export control decisions can be very difficult, and you have to get the right expert advice and counsel with respect to the laws as they are written and the technology in question. Sometimes it is very useful to go and sit down with the people in these organizations to help them understand the technology in question so that they can be assured that there is not, in fact, a strategic disadvantage or national security risk in approving the sale or cooperative arrangement that is being proposed.

Question: I wondered if your experience had given you some insight into what the impact would be on the national laboratories if Congress continued with the stated intent to recompete the management of all of them.

Bernthal: I probably should take the Fifth on this one. One of the things that I have learned in my 25 years in Washington is that worst-case scenarios almost never happen, but of course you cannot take that for granted. What is being referred to, by the way, in the question is the language in the Energy and Water Appropriation Bill in the House that would mandate the competition of virtually all the national laboratories that the DOE runs, including Fermilab, for which we at URA are responsible. I will duck your question a bit because, as a practical matter, DOE is simply not equipped to compete all of these contracts in anything like a short period of time. That said, however, they certainly could carry out a competition of every single laboratory in seven or eight years; that's not hard to imagine. The issue I hope both houses of Congress will recognize is that competition for the sake of competition—just to say "you did it"—is not necessarily a wise thing to do. One might recall the early purpose and principles behind the formation of the so-called Federally Funded Research and Development Centers (FFRDCs), which were to foster long-term cooperation and partnership. There was a recognition and understanding that the government and the Department of Energy (or the AEC as it was then called) especially needed the intellectual contribution of the universities and needed as well the help of knowledgeable industrial partners. And so that was the original philosophy, which gave rise to the now long-standing cooperation between DOE and its laboratory contractors from industry and academe.

Now I am prejudiced of course, but I happen to think that, more than ever, the agencies of the government need the intellectual base of the universities in the operation of their research enterprises, if those laboratories are to survive and prosper over the long run. That is just my view of the world; arguably things are quite different in terms of budgets and many other respects in the national labs than they were in the Cold War years. But I hope I have given you a sense of the factors that should be considered in debating this issue. By the way, a blue ribbon commission, appointed by the Secretary of Energy, will issue a report on this subject within the next few weeks.

Question: Could you comment on the trends in globalization? Where do you think that we are going? What can major governments do?

Neureiter: I would like to point out the difference between the business world and the political world. I mean, countries are getting smaller and more numerous, aren't they? And businesses are getting bigger. I talked to John Young (former chairman of HP) about it last night. I told him my little story about HP and Compaq merging and I said, "Why couldn't Exxon and Mobil, at $181 billion in sales now that they have merged, compete separately in world markets at $90 billion dollars apiece or something like that?" His answer was, "It is a question of risk management. It isn't being unable to compete. It is in the risk you take in putting in one of these giant facilities and platforms." I was on a big Chevron platform a couple of months ago in the Gulf of Mexico. It was an incredible affair—the resources coming out of this one platform are immense. And yet, it is a billion-dollar investment, so if something happens or it does not work or it sinks, it is a huge problem for the one company that has made the investment.

With globalization, in general, I think we are at a very perilous stage. Clearly there is a reaction taking place to this move toward globalization and one form of that reaction is terrorism. My great fear in all of this is that we turn this into a battle of civilizations. I judge from your pronunciation that you have a Middle Eastern background, so you know the tensions in that part of the world and what that means. We are a long way from tempering conflict in that region. On the other hand, it is amazing but true that if there is a product available and there is a market for it, somehow the two will find each other. We spend in the United States $30 billion a year trying to stop drugs from coming in, and they still come in. But if you shut down the market—if there were no demand—they would not come in. I think that this is the saving grace for the corporate world particularly in the petroleum business. If there is a market, somebody is going to find a way to get the product to the market. Remember the panic that went through the world in the 1973 oil crisis? But suddenly all of the money was being re-circulated and now somehow these oil-rich countries are running a deficit. I think we are living in a very turbulent time, a troubled time.

Question: Bernthal talked about the labs being an intellectual enhancement for the normal government structure. And your point about bringing more fellows into State was certainly in line with that kind of reasoning. I think that your steps in that direction were a very major effort in State and probably ought to be expanded throughout government even more widely.

Neureiter: I am so pleased that you said that. In fact, I wanted to stick an advertisement in at the beginning of my talk for any students who have not gone off for the weekend and who are interested in this opportunity. If there are any, they should go to the State Department website and look at the fellowship and intern opportunities that are available there. They are getting to be significant. Or go to the American Institute of Physics, IEEE, American Chemical Society, or the Industrial Research Institute websites and see what they are doing in this area. The AAAS program is, of course, on their website. And these are not just limited to fresh Ph.D.'s. or graduate students. These can also be for senior people who would like to take a year off and dip their toes into the murky waters of Washington policy.

Dresselhaus: Sometimes they return to their home base and they contribute in other ways. There are two ways: one is to do government service later and the other is to contribute to the community. That is the civic scientist we are talking about here.

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We would like to acknowledge all of the hard work that went into the preparation of this manuscript. First we wish to thank all the co-sponsors for the event (National Science Foundation, Los Alamos National Laboratory, James A. Baker III Institute for Public Policy, and the Department of Physics and Astronomy at Rice University). We would also like to specifically thank those who organized the event including Umbe Cantu, Pat Reiff, Ryan Kirksey, Jillene Connors, Kirstin Matthews, and Amy Jaffe. We appreciate the work by our Rice student volunteers, who were helpful during the workshop. In addition, we would like to thank the staff at the Baker Institute for reviewing and preparing the manuscript for printing. Finally, we would like to thank all of the former students of Neal Lane who wanted to do something special to commemorate Neal Lane's 65th birthday.

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IN MEMORIAM

Since the conference was held in 2003, we were saddened to lose two of our distinguished speakers and great friends, D. Allan Bromley and Richard "Rick" Smalley, both of whom died in 2005. We offer this manuscript in their memories. Allan and Rick served science and our nation, and in the course of their lives they inspired many others to do the same. Both men were committed to seeing a better world through science and worked to influence the process of public policy to deliver that world. Their contributions were enormous and their loss will be strongly felt by both scientists and policy makers.

One of the world's leading nuclear physicists, D. Allan Bromley was a Professor of Physics at Yale University starting in 1963. In his career, Allan carried out pioneering studies on both the structure and dynamics of nuclei and is considered the father of modern heavy particle physics. In addition to a distinguished scientific career, Allan was a strong advocate for science and shaped science policy while serving as the Assistant to President G. H. Bush for Science and Technology and Director of OSTP from 1989-1993. D. Allan Bromley died on February 10, 2005 at the age of 78.

Richard "Rick" Smalley was a Professor of Chemistry and Physics at Rice University since 1976. One of the most distinguished scientist of his time, Rick was widely known for the discovery and characterization of C_{60} (Buckminsterfullerene or buckyball). His discovery, together with Robert F. Curl and Sir Harold Kroto, spurred the development of nanotechnology, a new area of science capable of solving global problems in fields ranging from medicine to energy to national security, and earned the team the Nobel Prize for chemistry in 1996. Rick's career was also marked by his strong advocacy for science. Long credited with guiding the establishment of the National Nanotechnology Initiative, Rick embarked in his later years to educate policy makers about the need for new energy and oil alternatives, which he hoped nanotechnology would help discover. On October 28, 2005, Richard Smalley died at age 62.

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