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Bridging the Gap between Science and Society

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 7 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 of 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 more than 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, threatening our future prosperity.

Electric power plants on the drawing board for the period 2010 to 2015 still will be in operation by 2050. The International Energy Agency predicts that more than $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 more than 20 billion tons/year 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 2 percent per year from 1 percent, the requirement for carbon-free energy in 2100 still would 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 preindustrial 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 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, the National Science Foundation (NSF), 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." The conference, held November 1 and 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 comprised more than 200 policymakers, scientists, opinion shapers, and business leaders. 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. In addition, the conference participants took the occasion to honor the contributions of Neal Lane, former director of the NSF 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 paper 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 during the two days.

With this qualification, this summary and the transcript report of the meeting itself highlight the need for the following: 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 among scientists around the world and, thus, be able to draw on the best and the brightest minds 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 always has 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 also are 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 on 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 2,000 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 0.7° C increase already observed (IPCC Third Assessment Report: Climate Change, 2001). In the last part of the 20th century, CO_2 levels rapidly increased. 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, such as 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 already are apparent. There is a rapid decrease in Arctic sea ice as well as land-based ice in locations 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 CO_2 could encourage more plant growth, it also could increase insect infestations due to the milder winters and forest fires due to drier conditions.

Climate change also will 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 rises 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—in government and industry—than we have had in the past. That will require significant multiyear 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 policymakers 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.

In the past, it has been proposed that a drop in government spending would be outweighed by a rise in private sector funding, but that has not been proven to be the case. 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 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 nontraditional 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 stop using petroleum products as its primary fuel, it must develop another fuel that can be transported easily 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 being investigated, with ethanol produced from cellulosic biomass or organic waste processed by thermal depolymerization appearing to be the most promising in terms of full-cycle energy use gains that result in real-time displacement of oil consumption. According to Oak Ridge National Laboratory, the United States generates more than 250 million dry tons of forest, crops, and urban wood wastes that could be recycled to produce more than one million barrels a day of transportation-grade biofuels.

Another attractive candidate for the principal alternate 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 in which 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 high-voltage carbon nanotube 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 recharge 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 farther 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 under way around the world. By 2015, there will be 49 cities of five million people or more compared with only eight cities of five million or more in 1950. 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 currently are 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. A Princeton University study, "Stablization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies" (*Science*, 2004), discusses the most viable approach. The study says that this would involve constructing 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 also would 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 GtC/year of carbon 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 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 nonfossil-fuel bearing formation. A major science effort is under way 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 eventually will be produced from renewable energy sources such as solar power driven reactors (to split water into hydrogen and oxygen). There remain, however, 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 Corporation has estimated that the capital infrastructure costs will run in the tens of billions of dollars. Shifting to a hydrogen economy also will require improvements in fuel cell technology, including lowering costs and finding better catalysts, chemical separations, and 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, and materials science; new polymeric and ceramic materials; revamped theory and modeling; and advanced 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 nonproliferation 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 nongovernmental terrorist groups. This includes three tasks: 1) protecting existing materials; 2) reducing and eventually eliminating excess stocks of weapons-grade materials; and 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 exist. 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 relied on increasingly 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, rather than the plants themselves, will have to establish clearer rules for the operation of nuclear power plants that define fuel cycles as the critical concern. 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 undoubtedly will 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 essentially is depleted, with too few undergraduate and graduate students and 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. And 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 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 precommercial 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. 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, such as 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, such as 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, for which, unlike other areas of science, the public seems to have 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 more than half of all federal research funding. In recent years, even NIH funding has not increased significantly, and in some years, it had declined compared to inflation. The former director of NIH, Harold Varmus, often has made the point that, since the new drugs and medical technologies come out of basic chemistry, physics, engineering, and other fields, we are underinvesting 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 necessarily argue 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 solutions 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 such as 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 nonweapons 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 also are areas in which the national labs have been strong. Their expertise in this area likely will 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 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 who, on 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 also is 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, 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 nontechnical fields, even in related fields such as healthcare and education. Science is not reaching the majority of the children in K–12 schools and young adults in colleges and universities. In the precollege 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 National 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 good 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 toward 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 nonscientists, including education majors, can expect only a shallow exposure to science, often graduating with neither in-depth understanding of the scientific process called 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 come only 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 not only among universities, the national energy laboratories, and U.S. industry but among researchers and organizations in the United States with 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 its 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 the immigration of these talented people. The poor quality of K–12 science and mathematics education also is 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 National Science Board, 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.

The 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, combined with 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 as energy to the future of the nation, the public and its elected representatives need to understand the issues, some of which are technical. Neal Lane often has 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 policymakers 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 often, perhaps usually, is 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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