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The BRIDGE
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LINKING ENGINEERING AND SOCIETY

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THE NATIONAL ACADEMIES

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

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

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

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

Editorial

George Bugliarello is chancellor of Polytechnic University in Brooklyn, N.Y.

Our Energy Future

The theme if this issue is energy. The problem is not that energy for our planet is in short supply. On the basis of what we know today, the world has enough coal, oil, and gas to last for centuries. And, of course, we can count on solar, wind, nuclear, and other forms of energy for billions of years. Biotechnology is another promising energy source. The problem is to ensure that energy is available where we need it (often far from its sources) at an acceptable cost and without doing irreparable damage to the environment. Regardless of where it comes from, it will require considerable resources and ingenuity to negotiate the technical hurdles. If it comes from far away, geopolitical hurdles will also have to be overcome.

The energy business is, and will continue to be, both risky and costly. It will require entrepreneurship of the highest order, which should be rewarded but also disciplined and channeled to ensure that distribution is reasonable and reliable and to avoid profiteering. One of the most difficult challenges facing a free society is striking a balance between necessary controls and a free market. In a market economy, the energy industry has demonstrated its ability to find new resources and convey them to users more effectively than state monopolies. Nevertheless, given human nature, unbridled laissez-faire can be dangerous; consider, for example, a case of food energy, as in the Irish famine, and a case of a speculative house of cards, as in the Enron collapse.

Public intervention is also essential for dealing with the externalities of health-damaging emissions and developing new energy technologies that cannot be commercially viable without incentives to encourage cost-lowering mass production. In establishing a fine balance between the free market and regulation, we must also take into account the plight of many desperately poor countries that will need inexpensive reliable energy to emerge from poverty. Public/private partnerships on a global scale will be necessary to make a fair share of Earth's energy resources available to them.

The difficulties will be exacerbated unless we can raise the level of scientific and technological literacy, so educated citizens can assess the facts and consider the options. The issues are complex, as is clear by the conflicting positions within the scientific and engineering communities based on different assumptions. Drilling in Alaska is a high-profile example, a case of economic development versus ecological concerns. With enlightened policies, technically literate citizens, and human ingenuity, harmonizing these conflicting goals should be possible. At least, disasters caused by the reckless mining, generation, and use of energy, as in the case of the former Soviet Bloc countries, should be a thing of the past.

Energy deregulation "does not have to end in tears," as Callon McCarthy, chairman of the British Office of Gas and Electric Markets, has put it. The separation of ownership between generation and distribution makes sense, but, as we learned in California last summer, disasters can happen if companies that buy at free-market prices are forced to sell at a capped price. Deregulation can reduce costs to consumers, but it is not a panacea. We must find new sources of energy, improve the quality of performance of distribution networks, increase the efficiency of energy generation, make the use of renewable energy more cost effective, diminish geopolitical conflicts, and reduce adverse impacts on the environment.

For the foreseeable future, we must be realistic about our choices. Coal will continue to be a major source of fuel; nuclear energy is so mistrusted by the public that its use will continue to be problematic, no matter what its merits; the use of gas will increase and thereby possibly increase some international interdependencies, particularly in Europe; the American public will continue its love affair with large energy-expensive personal vehicles; emerging technologies, from fuel cells to wind and solar energy to carbon sequestration, promising as they are, will require incentives to be used on a meaningful scale and, thus, reduce global warming. And, of course, the protection of energy supplies, generating installations, and distribution systems will be an enduring concern.

Each of these facts of life will raise major engineering challenges. Engineering expertise in systems analysis, design, and risk assessment will be urgently needed to inform public policy and inject a sense of realism and possibilities in the continuing debates about our energy future.

George Bugliarello

We should adopt an "investing in the future" approach to energy rather than the current "borrowing from the future" strategy.

New Energy Frontiers

Richard H. Truly is a member of the NAE and director of the National Renewable Energy Laboratory. This article is based on a presentation given at the Technical Session of the NAE Annual Meeting in October 2001.

Richard H. Truly

America's energy enterprise is the lifeblood of our economy and our daily lives and is at the heart of our national security and survival as has been vividly brought home to us in these past frightful months. Coming on the heels of two years of power shortages and price volatility, the events of September 11 have triggered changes in how we value energy and how we think about energy issues. These changes will not be short term or temporary.

Energy transformation and use are all about engineering. In the past American century, we witnessed one engineering marvel after another. Engineers turned imagination into reality in so many ways: from automobiles to powered flight, from the construction of cities on Earth to exploration of our moon and planets, from the building of interstate highways to the creation of the Internet; and today engineers are bringing biology and engineering together. These and a thousand other things have created a gargantuan demand for energy. How will we meet our growing demand for energy? Why should we change from the energy system we have today? To answer these questions, we have to take a moment to appreciate our current sophisticated energy enterprise and its consequences.

The United States uses about a hundred quads of energy every year, and every American uses about six times the world average. Our energy consumption is divided roughly equally among transportation, buildings, and industry. About 73 percent of our energy is produced in the United States, 85 percent of it from burning fossil fuels. Although we have more than 100 nuclear power plants, coal still generates more than half of our national electricity. In my home state of Colorado, coal provides 83 percent of our power. Despite the current dominance of coal, however, most new electricity generating capacity is fired by natural gas. To transport our energy, we rely on 400,000 miles of oil and gas pipelines and 160,000 miles of long-distance high-voltage transmission lines. Our natural gas and electric industries are undergoing restructuring, and recently, Americans have experienced high volatility in the prices of electricity, natural gas, and gasoline. Our transportation relies almost exclusively on oil, nearly 60 percent of which arrives in tankers from abroad, and that percentage is climbing.

Our current approach is not as risk-free as it appears.

The argument for continuing with this system goes something like this. It would be generally less risky—and more likely to yield returns in the short term—to build on existing energy technologies and infrastructures than to switch to new ones. And given the projected abundance and relative low cost of fossil fuels, a "business as usual" approach seems very plausible. If we adopt higher efficiency processes and new technologies that recover marginally economical resources, we can minimize the impacts on future generations for some time to come. We could also manage wastes better and further reduce traditional pollutants, such as nitrogen oxides (NO_x), sulfur oxides (SO_x), and particulates. In short, our current approach appears to be low in risks and regrets.

Changes on a Planet-Wide Scale

My concern is that, in the long term, this scenario might not be as risk and regret free as it appears. We would remain heavily dependent on depletable fossil hydrocarbon resources that would have to be extracted from increasingly remote and distant places. Someday, the incremental increase in the cost of finding the next unit of increasingly scarce fuel will reach a point of diminishing returns, putting upward pressure on costs even with sophisticated recovery methods. By adding wastes to our sinks of land, water, and air, we will certainly experience adverse consequences to our economic and ecological systems. But the most daunting ecological uncertainty from the combustion of fossil fuels is that it accounts for 75 to 80 percent of the carbon dioxide (CO_2) released to the atmosphere resulting from human activities. Our engineering choices for reducing CO_2 are limited. Either we can significantly reduce or eliminate them, or we can sequester CO_2 to offset potential global climate changes. Or we can wait and see and hope for the best.

What about the risks to our energy security? The events of the past few months have vividly reminded us of the vulnerabilities of our current energy infrastructure. As a nation, we rely on an extensive and complex energy infrastructure, much of it vulnerable to acts of terrorism, accidents, and acts of nature. In my view, energy security is national security.

But to understand the situation in our own country, we need to step back and look at it in a broader context. Global population recently passed the 6 billion mark. A National Research Council report in 1999 estimated that, by 2050, the population will increase to about 9 billion and will still be growing, although more slowly. The great majority of this growth will occur in developing countries, rather than industrialized countries. The most urgent needs of people in developing countries, many of whom have no electric power today, will be for clean water, clean air, adequate food, and good health. These needs will take priority even over education and the search for ways to provide and build a decent living. People everywhere see our standard of living and want it for themselves.

If these economies were actually able to raise their standard of living to a standard anywhere near that of industrialized nations, global per capita energy consumption would soar, and the rate of energy consumption would far outstrip the rate of population growth. Therefore, it is in our interest to help find a way to meet this huge demand for new energy, particularly in the emerging megacities across the globe. Ensuring that people everywhere have a secure, sustainable, acceptable quality of life may be the most critical engineering challenge we face today.

Perhaps the most compelling evidence of the effects of our life style on the Earth can be seen from space. Twenty years ago next month, I lifted off on my first space mission aboard Columbia. My first real view of

Earth was both beautiful and startling. From the Los Angeles Basin to Mexico City to Tokyo, the effects of humankind's energy emissions were visible and sobering. In January 2002, in a BBC interview from Earth orbit, U.S. astronaut Frank Culbertson, the commander of Expedition Three aboard *Space Station Alpha,* noted that in the last 10 years the view of Earth from space has changed markedly. Earth is increasingly marred by smoke and dust, and environmental destruction is increasingly visible. Culbertson believes the changes are a cause for great concern, and I couldn't agree more. The National Academy of Engineering also recognizes the importance of these issues and has established a new Earth systems engineering initiative to assess energy production, environmental engineering, and global change.

The Importance of Earth Systems Engineering

Based on these observations, facts, and projections, I have concluded that our current "business as usual" approach should be called the "borrowing from the future" approach. The current energy situation reminds me of Edna Saint Vincent Millay's famous stanza about herself: "My candle burns at both ends;/It will not last the night;/But ah, my foes, and oh, my friends—/It gives a lovely light!" Although it is, indeed, a lovely light, we are depleting our storehouse of fossil fuels, become increasingly reliant on vulnerable infrastructures, and are continuously adding wastes to our environment. Although we have little choice but to continue down this path in the very short term, we are creating debts for future generations.

A New Energy Destination

I believe our most important task for the future is to define a new energy destination and chart a course for it, even if the journey takes half a century or more. I invite you to imagine with me the attributes of our grandchildren's arrival point. The energy destination will be affordable, flexible, and reliable enough to meet the changing needs of a diverse population of energy consumers in a predictable manner. It will be as secure as possible from disruptions from acts of terrorism and nature. It will be safe and environmentally clean enough that it does not overtax Earth's ability to handle wastes, and it will be extremely energy efficient in production and use. It will rely on a mix of fossil, nuclear, and renewable energy sources, in a combination that emphasizes sustainable resources. But the acid test of success is that it must support human activities at a standard of living equal to or better than today's without reducing options or incurring debts for future generations. This is a tall order, but I think it is imperative that we raise the bar—now—to this level of expectation.

Our current energy system will not change quickly, and, considering our utter dependence on it, should not. But I believe we must begin the transition, and it can be made with far less risk than the risk of staying the course of our current "borrowing from the future" condition. I call the transition strategy "investing for the future."

Transition to a Sustainable Energy Future

Human history is defined by major transitions. We should expect and, perhaps, even welcome them by now, but change is difficult and skepticism abounds. As Arthur C. Clarke, the famous futurist and science-fiction writer, observed, "People tend to overestimate what can be accomplished in the short run but to underestimate what can be accomplished in the long run." A low-risk transition to a sustainable energy future will have to combine modest, well planned investments in new technologies with enlightened public policy to create a flexible portfolio of options that will lead to incremental changes in the near term and paradigm shifts in the long term.

So what are our options for creating a new destination with these attributes? First, although our future energy supplies will include fossil, nuclear, and renewable energy sources, our destination attributes will require a much different mix than we have today. Second, we will have to increase substantially the efficiencies of both energy production and end use. Third, we will have to find ways to mitigate the environmental consequences of fossil and nuclear wastes. And, because renewable energy is not completely free of environmental consequences, we will have to minimize those impacts as well. Fourth, increasing our indigenous energy resources can improve our energy security and stability by reducing our reliance on fuels imported from afar.

The transition strategy could be called "investing for the future."

Another significant option for improving our security is to reduce our reliance on large, interdependent central energy production and delivery systems. In fact, we can already begin to move toward more distributed energy systems that are networked but can operate independently if necessary. Distributed systems will provide both increased security and improved reliability. More efficient use of energy can protect us against volatility in energy prices and reduce energy costs.

Strategic Considerations

Strategically, the transition will require market momentum, sound public policy, and a commitment to research and development (R&D). Because our energy future will evolve from our existing infrastructure, the change will be gradual, the result of incremental changes over a long period of time.

The transition will ultimately have to be market driven. Markets, which tend to address consumer needs directly, can make things happen, and a market-driven transformation is likely to be persistent in meeting consumer needs. Today, for example, international markets are leading the way for renewable energy and creating growing opportunities for U.S. technologies.

Any strategy will fail unless we are committed to a revitalized national R&D program.

But sound public policy must also play a key role in the transition to a sustainable energy future. Markets deal with the here and now but do not have a planned destination, which is the role of a stable, well considered public policy. It is evident from the current proposed national energy policy, and proceedings under way in Congress, many states, and at the National Academies that policy discussions are well under way. Important early considerations should be to provide incentives for early adopters (consumers and industries) of available technologies (1) to lower their risk and reduce their long-term investment and (2) to accelerate the development of new technologies.

Even if the strategy is market driven and based on sound public policy, it will fail without a commitment to a revitalized national R&D program. R&D will be the third component—the underpinning for bringing promising technologies to the marketplace. First, we must invest in basic energy research. Basic science, which provides the fundamental foundations for technological breakthroughs, is a powerful tool in the creation of new products for the marketplace. Scientific research also provides a degree of technological insurance against unpleasant surprises, such as global climate change occurring faster or causing greater consequences than predicted.

Second, we will need substantial improvements in smart operational systems integration (another NAE initiative). Our current electric grid was designed mostly for the one-way flow of electricity from central station power plants to consumers and is fairly vulnerable and inflexible. The electricity infrastructure of the future will have to be more networked to provide the services and meet the security needs of future energy customers. The infrastructure should be integrated, intelligent, and capable of two-way power flow so that the full value of distributed generation can be realized.

Third, the R&D development program must actively demonstrate through pilot-scale tests and field demonstrations that new technologies work. Technological uncertainties may represent risk, and failure can lead to economic penalties, safety risks, or damage to equipment. Pilot-scale tests and field demonstrations can significantly reduce the likelihood of early commercial failures. Scientists and engineers will be essential to a successful transition. America's best and brightest engineering and science professionals and students must be engaged in this endeavor.

Signs of Change

In some ways, the transition has already begun. You can see signs of this in marketplace trends, changes in policy, and emerging technologies. Consider market trends. U.S. energy consumers have always demanded low-cost energy, but with the advent of the information age and increasing business competition, they have been demanding new and much higher standards. As a result, *lowest price* is no longer the only concern of modern energy consumers. Large numbers of businesses and even homeowners are demanding unprecedented levels of reliability and quality, driven partly by round-the-clock business practices and a greater reliance on digital appliances.

The energy director of Oracle Corporation, Jeff Byron, explained it this way. “It is not the cost of electricity that drives our decision-making process, it is the cost of not having electricity.” Oracle, like many other companies, must operate 24 hours a day, seven days a week. A very brief, even a millisecond, glitch in the electric power supply can result in staggering costs for chip manufacturers, stock brokerages, communications firms, and biotech companies. This fact of life is also true for many process industries, such as the pulp and paper and plastics industries, for which computer process control is becoming commonplace. Today’s electric infrastructure, which typically provides “three nines” reliability (equating to outages of 9 hours per year) was simply not designed to provide the high quality service these customers need. We will have to find different solutions. Customers are also increasingly demanding more choice as to who supplies their electricity and new energy products, such as “green” power and highly efficient appliances.

In energy policies, significant changes are emerging at all levels of government. Although major energy bills making their way through Congress differ in many specifics, they also have many common elements: incentives to encourage greater energy efficiency, expand production, and use clean energy technologies; and R&D on distributed energy resources. The issues of deregulation and competition are being addressed partly at the federal level and partly at the state level.

New Technologies

New developments in technologies may provide the best evidence of changes to come. In the electricity sector, for example, the costs of wind energy has been dramatically reduced. Wind and photovoltaics are now the fastest growing generation technologies (annual rates of more than 30 percent) in the world. Photovoltaic efficiencies have steadily improved, with some technologies operating at 34 percent, almost competitive with fossil and nuclear conversion figures. Photovoltaics are rapidly penetrating the distributed energy markets, and residential photovoltaic systems can be purchased now at Home Depot. Fossil-renewable hybrid energy sources have been proposed as a way to accelerate the market penetration of renewable energies and thus reduce the environmental impacts of fossil fuels. Codes, standards, and deployment barriers are being reevaluated. Advanced nuclear technology concepts could lead to greatly improved nuclear power plants that are inherently safe and offer greatly expanded power and industrial applications. Using the tools of modern biology, such as genomics and metabolic engineering, we are creating new, more efficient ways of converting biomass wastes and energy crops into useful products. Biorefineries, the direct analogs of petroleum refineries, will be developed to produce biofuels, biopower, and commercial chemical products—all derived from biomass rather than fossil fuels.

New developments in technology may provide the best evidence of changes to come.

In the transportation sector, a new generation of hybrid electric vehicles is emerging that provides safety, comfort, and performance, all at greater efficiencies. Cleaner fuels are being developed from both fossil fuels and homegrown renewable sources. In the next decade, electric-drive vehicles powered by clean-burning “engines,” such as fuel cells, could become an integral part of the power-grid operation by functioning as distributed energy resources when “parked” near buildings.

In the buildings sector, electrochromic windows that can be darkened or lightened to control heat from the sun, desiccant-based dehumidification systems that reduce cooling loads, and solar cells integrated into the roof and windows will all help reduce energy demand in buildings. Improvements can be taken a step further with a whole-building design. Eventually, we could have “zero energy buildings” that produce the equivalent amount of the energy they use.

In the industrial sector, we are developing more energy efficient ways of manufacturing and recycling primary metals, such as aluminum and steel. Through combined heat and power (using heat for both space heating and even space cooling), we can realize further gains in fuel efficiency. The result will be a significant improvement in energy efficiency and reduced environmental impacts.

Hydrogen energy could play an important role in all of these sectors, and many energy experts think hydrogen will be the hallmark of our energy destination. In public-private partnerships involving industry, national laboratories, and universities, we are developing technologies for producing, delivering, storing, and using hydrogen. Early hydrogen production will come mostly from fossil fuels, but we are making progress in producing hydrogen from sustainable sources, such as biomass and solar energy. Crosscutting hydrogen technologies will eventually blur the lines between the electricity, natural gas, and transportation industries and will require an integrated energy strategy.

Commitment to Success

Having defined a destination and charted a strategy, we must also make a commitment to success. In this, we should be guided by four principles:

- constancy of purpose to avoid the delays and setbacks caused by changes in the objectives and rules for R&D programs
- recognition that we will need more than one energy solution; we must set performance goals and begin working on as many of them as possible, with ongoing reevaluations of their progress toward meeting our national vision and goals
- consistency of R&D funding, including making mid-course corrections based on the achievement of goals rather than on short-term political or economic considerations
- proactive provision of solutions for developing countries before they become overly dependent on the type of rigid system we have today

If we stay the course, public policy and science and engineering will pave the way for markets to embrace clean, secure, reliable energy technologies. This candle will last the night!

A sustainable, diversified energy future will depend on the wise use of new technologies.

The Energy-Environment Nexus

Rita A. Bajura

Rita A. Bajura is director of the National Energy Technology Laboratory. This article is based on a presentation given at the Technical Session of the NAE Annual Meeting in October 2001.

The mission of the National Energy Technology Laboratory (NETL), one of the U.S. Department of Energy's (DOE's) 17 national laboratories, is to develop improved technologies for fossil-fuel energy supply, delivery, and end use. NETL implements all of the programs for DOE's Office of Fossil Energy, and a few for the Office of Energy Efficiency and Renewable Energy, through an onsite research program and through contracts with industry, universities, and other laboratories. NETL focuses on technologies for generating electric power from coal, clean liquid fuels, and natural gas. The lab has more than 1,000 research activities in all 50 states and in several foreign countries.

Figure 1 shows the U.S. electricity generation mix from 1950 to 2000. Fossil fuels provide more than 70 percent of our electricity—52 percent from coal, 16 percent from natural gas, and 3 percent from oil. The issue facing us is how we as a nation can move toward a more sustainable electricity future. The word "sustainable" means different things to different people. To some, it means integration of the social, economic, and environmental domains. To some it means energy that lasts forever. And to some it means energy with no environmental cost for its production and use. Energy from every source has environmental or cost consequences. The challenge for us as a society is to agree on a practical definition of sustainability and then to develop a road map to achieve it. The road map should include public policies, incentives, and research and development (R&D) agendas.

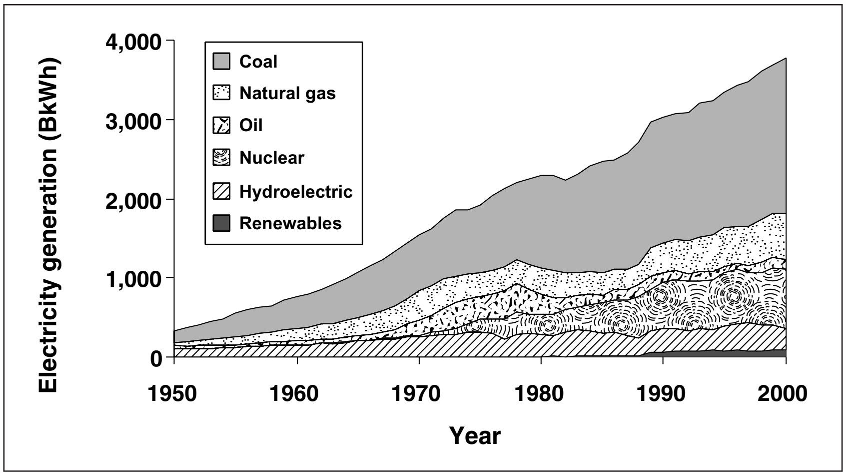

FIGURE 1 Electricity generation, 1950–2000.

New technologies have dramatically reduced the environmental impact of exploration for and production of natural gas. Industry today drills fewer wells to supply the same level of resources; at the same time, they produce less drilling waste and less wastewater. Using slimhole drilling, wells now have smaller footprints and cause less damage to unique and sensitive environments. In addition, air pollutants and greenhouse gas emissions have been reduced.

Using new technology, industry is working to further reduce the environmental impacts of oil and gas production. Consider, for example, horizontal and directional drilling. Horizontal wells would enable a hypothetical driller in the center of the District of Columbia to tap gas six miles away in Maryland. The use of this technology has risen sharply. In just 10 years, the number of horizontal wells increased from near zero to 4,000 per year.

The environmental impact of mining coal is also being reduced through improved planning, groundwater management, reclamation practices, and increased use of coal-mine methane.

As the U.S. energy industry moves toward internalizing most externalities, an increasing focus is on emissions of greenhouse gases. Figure 2 shows atmospheric concentrations of carbon dioxide (CO_2) and

In the past 30 years, the U.S. electricity sector has made excellent progress in improving air quality. From 1970 to 2000, coal use tripled, electricity generation increased by a factor of two-and-a-half, and natural gas use increased by 50 percent. On a tons-per-year basis, nitrogen oxide (NO_x) emissions from power plants have been declining since 1980, sulfur dioxide (SO_2) emissions have dropped by almost half since 1970, and particulate emissions are about one-tenth of what they were in 1970. Technology is now commercially available to reduce NO_x and SO_2 to very low levels. The nation is moving toward requiring all fossil-fuel plants to install NO_x and SO_2 pollution-control equipment. The National Energy Policy proposed three-pollutant control legislation for SO_2, NO_x, and mercury. Under the reduction levels being considered, SO_2 emissions would be one-ninth of their 1970 level, and NO_x emissions would be one-fourth of their 1970 level. Of course, these stringent reductions would not be without cost, but we have the technology—and the regulations appear to be coming—to make urban pollution a non-issue.

Global contaminants are an issue, however—especially mercury. The global atmospheric circulation of mercury is 5,600 tons. Utilities in the United States release 41 tons of mercury per year, one-third of U.S. anthropogenic emissions. Proposals have been made to cap mercury emissions at 7.5 tons per year. Achieving this level of reduction will be extremely challenging in terms of cost, timing, and uncertainty of the science of mercury. No commercial mercury-control technologies are available today, but field-scale tests are under way.

The concept of sustainability includes not only air emissions, but also resource production.

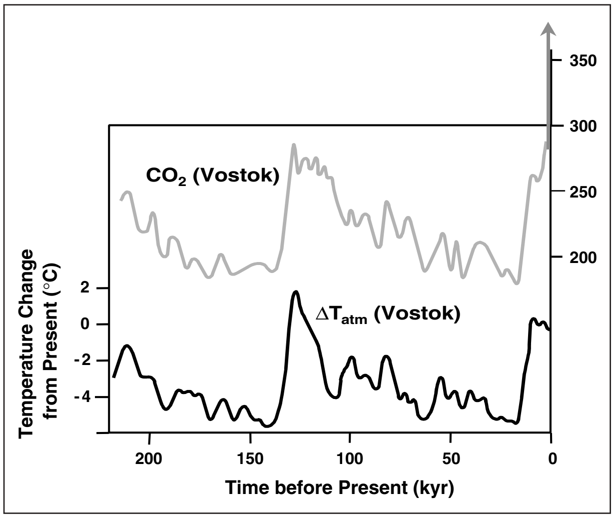

FIGURE 2 CO_2 concentrations beyond range of natural occurrence, 1800–2000. Source: Barnolo et al., 1999.

temperature fluctuations as measured from ice core samples at the Vostok station in Antarctica. Current CO_2 levels are at 370 ppm—a 30 percent increase over preindustrial levels and higher than at any time in the past 200,000 years. The two curves show that CO_2 concentrations and temperatures are correlated, although cause-and-effect relationships are not entirely clear. Nevertheless, the rising concentration of CO_2 is cause for concern, and CO_2 from energy production and use is a major contributor. We know that the production and use of fossil fuels are responsible for most anthropogenic greenhouse gas emissions. In the United States, CO_2 from energy accounts for 82 percent of U.S. emissions. Methane (9 percent) and N_2O (5.6 percent) are also significant contributors.

World demand for energy is growing rapidly, but, as history has repeatedly shown, it is difficult to predict future energy demand. In the next 100 years, world energy demand will increase to support growing populations and aspirations for higher standards of living. Demand in industrialized countries may double. Demand in developing countries may increase eightfold, although per capita energy consumption in developing countries will still be much lower than in industrialized countries. Overall worldwide energy use may increase fourfold.

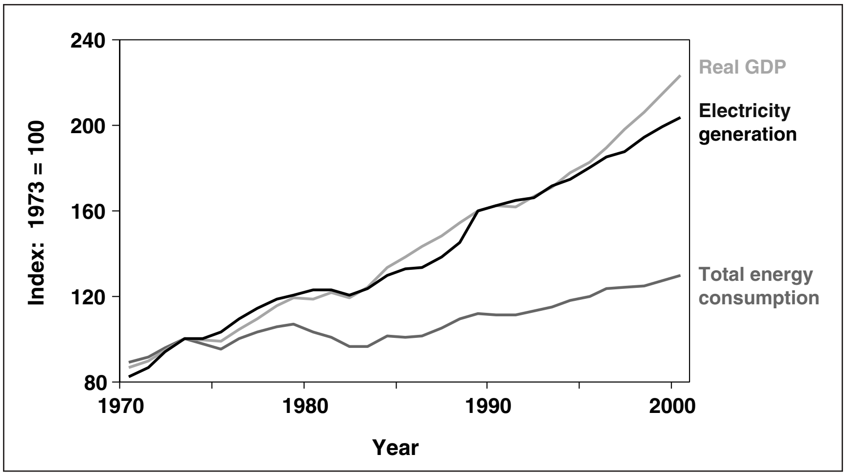

FIGURE 3 Economic growth and electricity, 1970–2000.

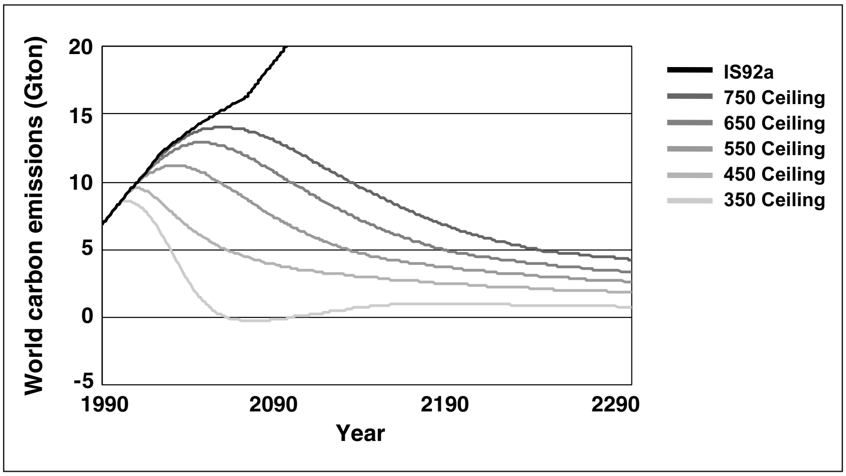

FIGURE 4 Reductions to stabilize CO_2 concentrations, 1990–2290. Source: Wigley et al., 1996.

Economic growth has been strongly linked to electricity consumption for the past 30 years (Figure 3). Electricity represents a growing fraction of our energy mix, and increases in electricity prices—and price volatility—affect the economy. In 1970, 25 percent of U.S. primary energy consumption was used to produce electricity. Today, it is 40 percent. The Electric Power Research Institute (EPRI) projects that it could increase to 70 percent as we evolve toward a future in which electricity provides all of our stationary energy and hydrogen provides our transportation energy.

Stabilizing atmospheric concentrations of CO_2 will require sharp cuts in emissions. Figure 4 shows worldwide CO_2 emissions. In the "business as usual" case (the IS92a curve), world carbon emissions rise from 6 Gtons/year in 1990 to more than 20 Gtons/yr in 2100; the atmospheric concentration of CO_2 in 2100 would be around 700 ppm, and rising. A more accurate name for the IS92a curve would be the "innovation as usual" case. It assumes, for example, that in 2035, we will be using large quantities of dedicated commercial biomass crops; the land area required for these crops will be 10 times the land area currently farmed in the state of Iowa. And these 10 "Iowas" will be growing crops with significantly higher productivity than today. The vast majority of renewable energy currently in the R&D pipeline is already assumed in this case.

The lower family of curves shows emission pathways to stabilize atmospheric CO_2 concentrations. The

550 ceiling curve, in the middle, shows an emissions pathway that would stabilize atmospheric CO_2 at 550 ppm, roughly double the preindustrial level. This is also the lowest level many analysts believe we can practically achieve.

Ultimately, emissions would have to be decreased to slightly more than 2 Gtons per year to maintain a steady state. This would amount to a 60 percent reduction from 1990 levels and a 90 percent reduction from IS92a emissions in 2100. A reduction of this magnitude would be a staggering undertaking, and, to achieve it, we would have to change our energy systems dramatically.

The electricity sector produces approximately one-third of current CO_2 emissions. The transportation sector also produces roughly one-third. The remaining third is produced by a mix of industrial, residential, and commercial emissions. Petroleum produces 42 percent of our emissions, followed closely by coal at 37 percent, and natural gas at 21 percent. Coal is the largest producer of emissions in the electricity supply sector. If emission caps are imposed at some future time, power plants may be expected to do more than their proportionate share to reduce emissions for several reasons:

- Electric power plants are among the largest point sources of CO_2 emissions.
- Because capital and management are centralized, the electricity sector might be easier to regulate than the industrial or transportation sectors.
- Electricity production cannot migrate offshore.

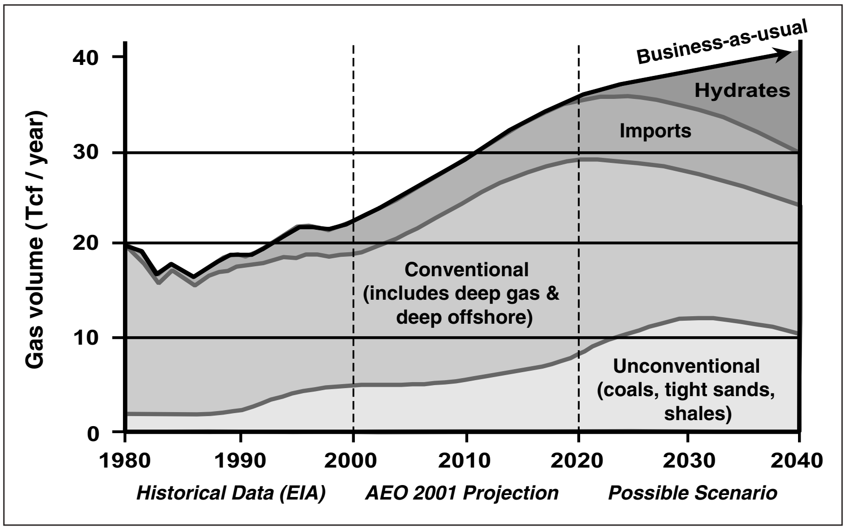

FIGURE 5 Supply and demand for natural gas, 1980–2040.

In addition, industrialized countries may decide to make earlier and sharper reductions than developing countries. Thus, it is plausible to consider a scenario in which the U.S. electricity sector is required to transition to a zero-emission world before other sectors.

The United States needs more power plants. Even with conservation, the National Energy Policy projects that we will need 400 GW to 600 GW of new power between now and 2020 to meet growing demand and to offset retirements. Four hundred gigawatts represents a conservative 1.8 percent per year increase in demand (in the 1990s, demand increased by 2.3 percent per year). Making the right choices for new power plants will be crucial, because investments in infrastructure have a lifetime of up to 100 years for transmission and distribution.

The electricity industry agrees that new plants are necessary, and for the first time in a decade, substantial numbers of new coal-fired plants have been announced. More than 40 GW of coal-fired plants are under development, most of them subcritical or supercritical steam plants. A few are fluidized-bed plants, and fewer still are gasification plants. Some of these plants were announced when natural gas prices were very high, and with today's lower prices, some may not be built.

Some renewable plants have also been announced, but the vast majority of new plants will be fueled by natural gas. The Utility Data Institute database of September 10 shows that 170 GW of new gas-fired capacity is under development (a conservative estimate). Other published estimates have been in the range of 300 GW. In a competitive electricity market, gas-fired plants are currently the lowest cost, lowest risk option. Even if all of these plants are not built, gas-generated electric power will certainly increase significantly. Many of these plants are large, base-load, combined-cycle units that use large amounts of gas.

Is there enough affordable gas to meet this demand growth? DOE's Energy Information Administration projects that gas use will rise to 35 trillion cubic feet (Tcf) per year by 2020 (Figure 5). Based on the recent "dash for gas," the number could be even higher. The issue is not supply in the ground but availability of infrastructure and the cost of producing gas as we tap into more unconventional gas reserves in more hostile locations.

Imports of natural gas have increased to 15 percent, but Canada and Mexico both want to retain more of their gas for domestic consumption. We could import more liquefied natural gas (LNG), but this is a concern in light of the events on September 11. If our oil supply is curtailed for long periods of time, natural gas would become the fuel of choice for the transportation sector—for producing gas-to-liquids fuels or for fueling LNG vehicles.

A common assumption is that we are quickly running out of fossil fuels and that there will be a rapid transition to carbon-free fuels. We are not! If technology continues to improve as it did in the past century, the world's fossil fuel reserves will last, at a minimum, for most of this century. In addition, if we can find a way to produce methane hydrates safely and cost effectively, we will have hundreds of years of supply. Supply is not the issue.

The issue is reconciling abundant, affordable fossil-fuel energy, which now provides 70 percent of U.S. electricity and 85 percent of our total energy supply, with the stabilization of greenhouse gas concentrations in the atmosphere. The solution lies in technology. We have four technological options for managing carbon: (1) reduce demand for energy; (2) reduce the carbon intensity of fuels (switch to less- or non-carbon-intensive sources of power generation); (3) increase the efficiency of energy generation and transmission; and (4) sequester carbon. I will focus on the last two options.

DOE is developing many options to increase the efficiency of power generation. In distributed generation, we are developing four different natural-gas-fired technologies: (1) fuel cells (more than 200 units installed worldwide); (2) fuel-cell/turbine hybrids (60 percent fuel-to-electricity efficiency in small units [250 kW]); (3) small turbines; and (4) microturbines. Distributed generation can be very efficient in combined heat and power applications and is likely to capture a larger share of the premium power generation market. Expanded natural-gas-fired distributed generation will require capital investment in the gas-distribution system to ensure electricity reliability.

Central station power plants will also remain an important part of the power generation mix, particularly in urban environments. Through cost-shared partnerships with industry, DOE is developing technologies to improve the efficiency of central power stations. The Vision 21 Program, for example, is developing energy plants for post 2015. A Vision 21 plant will use coal, natural gas, or biomass to produce electricity and possibly other products, such as liquids and process heat. DOE is also developing a technology base for highly efficient combustion turbines that can use natural gas, gasified coal, or biomass. As efficiency improves, CO_2 emissions decrease. In 1999, the average fleet efficiency for coal-fired power generation was 33 percent. By 2015, Vision 21 coal plants should achieve efficiencies of 60 percent, nearly twice the 1999 average. Turbines fired with natural gas emit less CO_2 than coal technologies because natural gas has less carbon than coal, and gas-fired combustion turbines are very efficient.

The issue is reconciling abundant, affordable fossil fuel energy with the stabilization of greenhouse gas concentrations.

Another option for stabilizing the amount of carbon in the atmosphere is sequestration, which could enable all fossil-based systems to reduce CO_2 emissions essentially to zero. Sequestration could decouple the use of fossil energy from greenhouse gas emissions.

There are two approaches to sequestering carbon. In the capture-and-storage approach, CO_2 is collected inside a power plant or other large point source and pumped elsewhere for permanent storage—in deep, unmineable coal seams; deep ocean; depleted oil and gas reservoirs; or saline reservoirs. The second approach is to enhance natural sinks. This approach is particularly useful for smaller sources, such as homes, cars, and small industries. Concepts being explored include reforestation, enhanced photosynthesis in algae farms, and iron or nitrogen fertilization of the ocean. Sequestration could contribute to the goal of the Framework Convention on Climate Change to stabilize CO_2 concentrations in the atmosphere.

We know that sequestration is technically feasible. CO_2 is already being used to enhance oil recovery at

70 sites in eight states; several more projects are planned. CO_2-enhanced oil recovery can be operated to leave the CO_2 in the geologic formation. More than 2,500 miles of dedicated pipeline now deliver CO_2 to fields, and upstream oil companies know how to handle CO_2. Most components of this technology are already commercially used.

Statoil, the Norwegian oil company, has been operating a commercial geologic CO_2 sequestration facility—the world's first—since 1996. Statoil strips CO_2 from natural gas produced by a well in the Sleipner oil field in the North Sea and sequesters the CO_2 by injecting it into a saline aquifer 800 meters below the seabed. The amount of CO_2 sequestered is equivalent to the amount produced by a 120 MW coal-fired power plant.

Pan Canadian Resources is starting a similar project at their Weyburn oil field in Saskatchewan. The CO_2 is produced as a byprouduct by the Great Plains Coal Gasification plant in North Dakota. This project may be the first international trading of "physical" CO_2 for emissions reduction.

For a sequestration method to be a viable public policy option, it must meet several requirements. It must be environmentally acceptable (i.e., it must leave no legacy for future generations, and it must respect existing ecosystems). It must be safe (i.e., there must be no risk of sudden large-scale discharges). It must include a way to verify the amount of CO_2 sequestered. Finally, it must be economically viable compared with other options for managing carbon. DOE's sequestration program is designed to address all of these requirements.

The economics of CO_2 sequestration can be improved with new plant designs.

Sequestration reservoirs underlie much of the United States, so most power plants are within a reasonable distance of a potential reservoir. Worldwide, the potential storage capacity for CO_2 is hundreds of times our annual emission rate. Annual world carbon emissions are about 6.2 Gtons. Estimates of storage capacity will change as we come to understand the science of sequestration—for example, the potential for changing the chemistry of the ocean. However, we believe that storage capacity is not an issue.

Funding for the Office of Fossil Energy's carbon sequestration program has grown from $1 million in fiscal year 1998 to an anticipated $32 million in fiscal year 2002. With nearly 60 projects in six research areas, we are exploring a range of options to see which ones will meet the four requirements discussed above. The program has generated a tremendous amount of industry interest; 40 percent of funding for recent projects has been provided by industry. Participants include industry (e.g., American Electric Power, Tennessee Valley Authority, and Consol), The Nature Conservancy, universities, and national laboratories. We recently awarded a $25 million, three-year project to a team led by BP Amoco, which includes Chevron, Texaco, and four European oil companies. The European Union and the companies are sharing in the cost.

The economics of sequestration can be improved with new plant designs that produce a concentrated stream of CO_2 at high pressure as part of the process. Coal-gasification plants could use a water-gas shift reaction to produce hydrogen for a combustion turbine and a concentrated stream of CO_2 for sequestration. Pressurized combustion using pure oxygen could also produce concentrated CO_2.

In a recent study jointly funded by EPRI and DOE to estimate the cost of an integrated gasification combined cycle (IGCC) plant with 90 percent capture of CO_2, the cost of electricity would be 5.6 cents/kWh. If the CO_2 could be sold for use in enhanced oil recovery, the cost of electricity would be less. If the CO_2 were injected into a geological formation, the estimated costs of transportation and injection would add 0.2 cents/kWh to the base cost.

For distributed generation, we are assessing a fully sequestered, 20-MW fuel-cell power park. The plant would operate in combined heat and power mode, providing electricity and process heat. Solid oxide fuel cells would be configured to produce a concentrated stream of CO_2 that could be shipped off site. Natural gas would be piped to the site.

IGCC technology for cost-effective sequestration is beginning to enter the commercial market. Worldwide, there is 70 GW of existing or planned gasification capacity. Of this, about one-third is sequestered by IGCC, which translates to 10 GW capacity. Two coal-

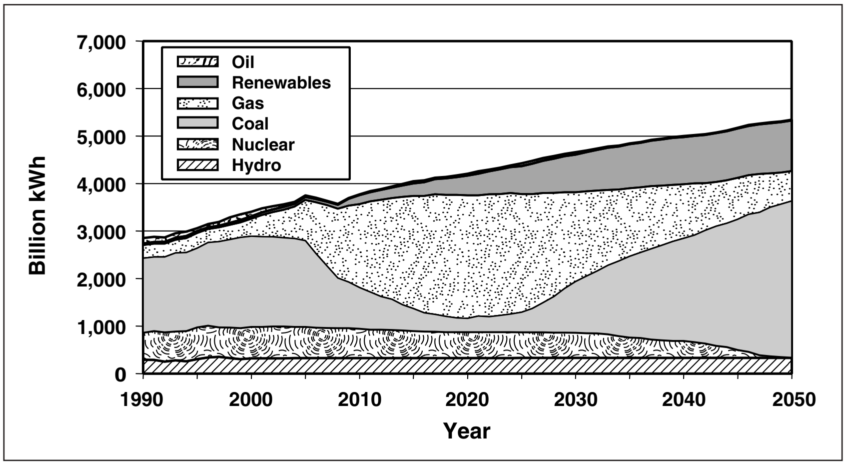

FIGURE 6 Scenario for U.S. electricity generation, 1990–2050. Source: EPRI, 2000.

fired 250-MW IGCC plants are currently operating in the United States, and we appear to be leaning toward this scenario.

Figure 6 shows the potential effects of increasingly stringent regulations on SO_2 and NO_x emissions and caps to reduce (modestly) CO_2 emissions. In this scenario, from the Electric Power Research Institute (EPRI) natural gas use would increase from 15 percent to 60 percent of our electricity generation over the next 20 years. Coal use would decline from more than 50 percent to 10 percent. EPRI concluded that, even if we could make this initial shift, we could not continue to rely this heavily on natural gas. When gas prices finally rise, new sequestered coal and renewable technologies would be introduced.

There are three problems with this scenario. First, it is a simplistic first strike at incremental reductions in CO_2 emissions. This scenario would not put the United States on a path to stabilizing CO_2 concentrations. Second, it would hurt the U.S. economy because both the gas and coal industries would be forced to abandon capital assets prematurely. Third, the United States would reduce its fuel diversity, a principle that has served the U.S. electricity industry well.

I believe it is essential that we resolve the environmental issues associated with fossil fuels, which provide 85 percent of our energy and 70 percent of our electricity. We cannot eliminate the biggest resource from the world market, at least for the remainder of this century. Fossil fuels will continue to be used domestically and internationally. I also believe that carbon management will be necessary to stabilize carbon emissions. As a public benefit, we should accelerate the development and deployment of more efficient fossil energy technologies that are sequestration capable. That way, if the United States decides to regulate CO_2 emissions in the future, we will have the technologies to do so. We must also support the transfer of these technologies to developing countries where the bulk of the growth in energy consumption will occur. I believe that no matter which pathway we finally choose for stabilization, we will be able to meet our target cost effectively with fossil fuels.

We must focus on all of our technological options for reducing the environmental footprint of power generation, and avoid simplistic, one-dimensional solutions. Technology will help us reconcile our economic imperative—the creation of jobs and wealth—with our environmental imperative—leaving the world not despoiled for future generations.

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President Bush's decision not to sign the Kyoto Protocol was good for the energy future of the United States.

Powering the Future

Pete Domenici is the U.S. senator from New Mexico. This article is based on a presentation given at the Technical Session of the NAE Annual Meeting in October 2001.

Pete Domenici

Although energy policy has taken a back seat since the terrorist attacks of September 11, the attacks highlighted weaknesses in the ability of the United States to withstand challenges to critical infrastructures. These attacks will force us to redouble our efforts to protect our population and the dependent infrastructure. Energy is in the class of systems to which we must direct careful attention to identify and mitigate threats.

In a sense, the attacks of September 11 set a new standard against which future terrorist activities will be judged. Unfortunately, we can be sure that terrorists will now set their sights on causing even greater disruption, loss of life, and human tragedy. That goal may, unfortunately, draw them towards using weapons of mass destruction or towards attacks on major nodes of our infrastructure on which many lives depend.

And yet we can't lose sight of our continuing energy challenges. Last year, blackouts in California were front-page news, and there was much talk about the crisis in energy. The situation has eased since then thanks to mild weather and increased conservation. Some have argued that the Senate should reconsider its stance toward the Kyoto Protocol, but the Kyoto Protocol is more of a political document than a serious attempt to solve a serious global issue.

The very real impact of terrorism will depress economic, and as a derivative, energy growth for a period of time. Although the urgency of an energy crisis has abated somewhat, the basic facts haven't changed. This nation and the world are facing immense shortfalls in energy in the short term and even more so in the long term.

Global Prosperity

World population will grow from the current 6 billion to around 10 billion in the next 50 years. The population of undeveloped nations will double from 4 to 8 billion in 50 years. Even if increases in per capita energy use around the world are modest, global energy needs will skyrocket. Some have argued that it is wrong for the United States, with 4 percent of the world's population, to account for about 25 percent of the world's GDP. Such arguments miss the point. America should be celebrating the strength of our system and our economy, which provides a standard of living that is the envy of the world. Even with the current setback in economic growth, the United States has a marvelous economic engine.

Certainly many elements have supported American growth—a free, democratic society; a judicial system that roots out corruption; a strong banking system; a strong middle class; and an innovation system in which entrepreneurs can explore new ideas for new products. A fundamental element of our economic strength has been cheap, reliable energy. Without energy, the U.S. economy would collapse.

In one respect, we can agree with those who criticize America's share of the world's GDP—namely that the United States should be helping to build up the economic strength of the rest of the world. America should be sharing its experiences and helping other nations strive towards our standard of living.

There are many reasons for wanting the economies of the world to reach our standards. For one thing, the American economy depends on having strong trading partners, and countries with high standards of living need the high-tech products that our companies produce. In the long run, a prosperous world with higher standards of living for more people may be the best possible defense against global terrorism.

Kyoto Protocol

By 2010, the Kyoto Protocol would place strict caps on greenhouse gas emissions for developed countries, especially the United States. Careful evaluations of the targets for the United States have shown that they would simply not be achievable without crippling the American economy. Kyoto puts no restrictions on greenhouse gas emissions of developing nations, despite the fact that their emissions will soon exceed those of developed nations. Kyoto would have the effect of crippling the American economy in favor of other economies of the world. That's why the Senate voted 95 to 0 on the initiative led by Senators Byrd (D.-W.V.) and Hagel (R-Neb.) to reject the Kyoto Protocol, even before it was submitted to Congress.

A fundamental element of our economic strength has been cheap, reliable energy.

Despite the headlines in the media about President Bush's announcement, all he did was restate the conclusion of the Senate. It's interesting that many of the senators who have criticized the president were part of that unanimous vote. If there is any doubt about the political nature of the Kyoto Protocol, one need only examine the recent Bonn meeting on that subject. At that meeting, there were still no limits on emissions from developing countries, but the penalties for developed countries that fail to meet their targets were dropped. In addition, one of the best options for new energy without greenhouse gases, nuclear energy, was dropped from consideration. It seems amazing that, at Kyoto, the Clinton administration managed to conduct the entire negotiation without ever mentioning nuclear energy. At least it was mentioned at Bonn, but only to ban its use in meeting emission targets. Consider also that France supported the Kyoto Protocol and the Bonn agreements, despite the fact that France generates 76 percent of its electricity from nuclear energy. These observations confirm the harsh reality that the Kyoto Protocol is nothing more than a sadly flawed political document, not a realistic path to solutions.

Prosperity beyond Kyoto

The U.S. Senate should stop arguing over "who lost Kyoto" and congratulate itself for not being trapped into signing it. At the same time, the Senate must recognize that the goal of limiting global greenhouse gas emissions is appropriate and begin to look for credible approaches that will not destroy the American economy. America needs to provide a blueprint for the world that identifies tools to combat global warming. Growth and prosperity in America are possible without global warming, and Americans can help provide those same benefits to the rest of the world.

As a country, America should provide worldwide leadership in eliminating the threat of global warming by making a long-term commitment to the development and use of clean energy sources. This goal should be accomplished through partnerships with our friends and allies, especially in developing countries. President Bush should lead this new initiative by accelerating American research and building international partnerships for joint development of clean sources of energy—renewables, clean fossil fuels, nuclear energy, and hydrogen-based fuels. As the United States transitions to improved technologies, its partner nations would also be building up their energy infrastructures with the latest and cleanest technologies.

America should seize every opportunity to help developing nations around the world achieve much higher standards of living, but they simply will not be able to do that without reliable electricity supplies. Each nation should make its own choices of energy sources, exploiting its own strengths. For example, America has abundant natural gas—which will make a huge contribution to a cleaner future. Other nations may be well positioned to exploit solar or wind resources. At the same time, every nation will need diverse energy supplies and must not rely on a single energy source. Through this program each nation could make its own choice.

> *It's in America's interest to help poor countries develop reliable, reasonably priced, clean energy sources.*

America has a choice. We can leave the poorest countries to their own devices and let them develop whatever energy they can, or we can offer substantial help and partnerships to help them develop sources that are not only reliable and reasonably priced, but also clean. It's in America's best interest to do this because, in the end, we all share the same air. And, as noted earlier, countries with strong economies will be our best trading partners.

"Beyond Kyoto" Legislation

The Senate is working on legislation towards this vision. A recent Senate bill would set aside $1 billion in loan guarantees to provide clean technologies for other nations. The bill would also establish joint research programs with developing nations to help them evaluate clean technologies. The proposal specifically favors projects in developing countries. For a developed country, the bill would require that, in a joint program, the other nation match the U.S. contribution. For a developing country, the U.S. would fund the research program and cover 90 percent of the loan guarantee costs. With this vision, America can achieve global "prosperity beyond Kyoto" and help other countries develop and use clean energy sources as they build their economies. As we move away from rhetoric over Kyoto's impossible short-term goals, we must build a solid foundation for long-term progress—a foundation that promises global prosperity.

Energy in the United States

We must focus not only on international energy issues, but also on our own energy policy. Our country and president were criticized at the recent meeting in Bonn because America generates 25 percent of the world's greenhouse gases—gases that are increasingly suspected of causing global warming. Many world leaders voiced concerns about the president's statements against the Kyoto Protocol.

Let's look at the record more closely. It's true that our 4 percent of the world's population generates far more than 4 percent of the greenhouse emissions. If you consider that America produces 25 percent of the world's GDP with about the same percent of global greenhouse gas emissions, you would draw difference conclusions.

Critics argue that America has not done enough to reduce greenhouse gas emissions—and they are right that a lot more can be done. But we have made immense strides that we should be proud of. We have also demonstrated that far greater efficiency is possible. In fact, since 1973, the U.S. economy has grown by 126 percent, while energy use has increased by only 30 percent. Critics who argue that we must hobble our economy to cut greenhouse gas emissions are way off base.

America can have prosperity and cut its emissions. The president's National Energy Policy describes research programs and tax credits to do just this. The recent Energy and Water Development Appropriations bill approved by the Senate provides excellent research funding. The president has been criticized because his National Energy Policy does not emphasize energy efficiency and conservation. But the critics are wrong. The National Energy Policy places a tremendous emphasis on energy efficiency. For example, if the current ratio between energy use and GDP were maintained, 77 percent more energy would be required by 2020. But the policy supports strong measures to improve efficiency and projects that we would actually need only about 29 percent more energy.

That National Energy Policy also addresses the very serious problems of the supply side of the energy equation. Estimates are that consumption of crude oil alone will increase more than 30 percent by 2020, with a disturbing fraction of that oil coming from regions of the world where the war against terrorism may disrupt supplies. And demand for natural gas is projected to grow dramatically as large numbers of new gas-fired electricity plants come on line.

Domestic oil production does not come close to meeting America's needs; in fact, it's down 40 percent over the last 30 years. In that same period, imports increased by a factor of 2.5 to about 57 percent. Our ability to refine oil appropriately has also declined; in the last 20 years, total refinery capacity has declined by more than 10 percent.

The Nuclear Option

There is one important option for increasing the production of clean energy that cannot be ignored—and that is nuclear energy, which already accounts for more than 20 percent of American electrical production. Nuclear energy provides this power without emitting airborne pollutants, with amazingly high reliability, and with costs even lower than coal.

Estimates are that, despite significant efforts to improve conservation and efficiency, we will still need to increase our electricity capacity by about 45 percent over the next 20 years. There can be no doubt that nuclear energy must be one key mode for meeting our future electricity needs. There are no credible options available to take its place.

Extensive legislation has been developed in the Senate to support and encourage future nuclear energy development. The legislation includes provisions supporting current nuclear plant operations, new plants, fair evaluations of nuclear energy, and better solutions for nuclear wastes.

Nuclear power is a source of clean energy that cannot be ignored.

Our current national policy for handling spent nuclear fuel is simply to put it in a permanent repository. The argument that this approach best serves our nation is not persuasive. After all, "spent" fuel still contains at least 95 percent of its initial energy content, and technologies are available to recycle that fuel and extract significantly more energy from it. These advanced approaches can not only recover the energy content, but can also dramatically reduce the toxicity of the final waste products.

Research and development are being done on advanced fuel cycles that could provide dramatic future benefits to taxpayers. These might involve reprocessing, now done routinely in many countries, and a process called transmutation, through which the toxicity of the final waste form placed in a permanent repository can be reduced to below the level of toxicity of the original spent fuel. The goal is to make waste products no more hazardous than the original uranium ore. The physical principles underpinning reprocessing and transmutation are sound, but the details of the economics and environmental impacts require further study to determine if this is the best path for our nation.

The Senate has advocated research and development on new types of reactors, such as Generation IV reactors, which would be very different from current reactors. They would be passively safe and absolutely incapable of a meltdown no matter what the circumstances. They would produce less waste and be more resistant to proliferation than our current reactors. They could also be much smaller than current plants, which means they could be buried to render them invulnerable to terrorist threats. They could be simple enough to be mass produced in factories. Cost projections suggest that these systems could rival the costs of natural-gas-fired plants.

Conclusion

There's no simple panacea for addressing the world's future energy needs or even those of just our country. The immense challenges facing the United States and the world will require careful attention to production, conservation, and efficiency. Where production is needed, we should focus on options that produce emissions as close to zero as possible. Nuclear energy should be a significant part of our overall energy portfolio, but the overall distribution of clean energy sources in that portfolio should be driven by the economics of each energy source.

America should seize the opportunity to move beyond arguments over the Kyoto Protocol toward strong programs to assist developing nations with new clean sources of economical energy. As we strengthen their economies, we will also be building a world in which the threat of terrorism can be vanquished and stability and peace will be possible for all peoples.

Deregulation works—but not the way it was done in California.

The California Electricity Crisis: Lessons for the Future

James L. Sweeney is professor of management science and engineering, Stanford University.

James L. Sweeney

California's disastrous experience with electricity deregulation cast a pall on movements towards deregulation throughout the United States. Some have said that the California experience shows that deregulation cannot and does not work, which is patently untrue, as an examination of energy, price, and demand data collected before and after the California electricity crisis shows. In this paper, I will describe what happened in California and the lessons to be learned from that experience. (A more complete discussion appears in my forthcoming book, *The California Electricity Crisis* [Sweeney, 2002].)

The California saga went through four stages, all of which presented the state with opportunities to make good and bad decisions. These stages were: (1) a risky situation that became (2) a challenge that turned into (3) a crisis that rapidly turned to (4) blight. Each stage, and in fact the whole process, should be seen not as a series of random, disconnected events, but as a sequence in which choices were made at each juncture. To address problems (often created by earlier policy decisions) at each juncture, alternative actions could have been taken. Given the political and economic forces at play, one can understand the logic underlying the decisions that were made. However, these decisions often created difficulties later. If different choices had been made at each juncture, they would have led to very different and probably much better outcomes.

In 1992, the California Public Utilities Commission (CPUC) began to develop a restructuring plan, which ultimately became the basis of California Assembly Bill AB1890, passed in September 1996. Although many California legislators have since decried this action, the legislature passed the bill unanimously. In fact, the process and the final legislation were not bad, but the implementation was severely flawed. California had very good reasons for restructuring its energy supply system. First, many experts believed that the vertically integrated system in place was not operating as efficiently as it could. Second, the system had very high costs. Third, the system did not seem to provide enough incentives for investments in new generating plants.

The restructuring began with the creation of a group of wholesale markets, with the understanding that deregulation had to begin with wholesale electricity transactions. To control these new markets, the legislature created the Power Exchange (PX) and the California Independent System Operator (CAISO). Creating markets for wholesale transactions was a sensible thing to do. The markets, however, were run as two separate organizations rather than as an integrated system, creating market inefficiencies and opportunities for market manipulation. In addition, retail price controls were established, which isolated consumers economically from the producers of electricity. At the wholesale level, California had created a volatile commodity market, but it had fixed sales prices for the investor-owned utilities at the retail level, a potentially untenable combination.

Cost changes at the wholesale level could not be passed on to retail customers.

A Risky Situation

The legislature and the CPUC believed that the "competition transition charge," a charge equal to the difference between the price-controlled retail price and the volatile wholesale price, would be sufficient for utilities to recover enough funds to recoup the stranded costs they had incurred prior to deregulation. These costs were mostly based on a combination of green-power contracts and nuclear power, two power supplies that had been costly under the old system. The CPUC also ordered additional transition charges to fund the public-interest activities required of the utilities, such as a public-interest research program and demand-side energy management programs. The utilities were also required to divest themselves of most of their generating assets, and it was made financially unattractive for them not to do so. This left the utilities with little generating capacity to fall back on.

Retail price controls meant that cost changes at the wholesale level could not be passed on to retail customers, which created the initial risky situation. Because of the rigid price controls in the new system, California utilities could not adjust to changing economic circumstances. With the sale of generating capacity, the risks were increased.

Once new wholesale markets had been created, someone had to use them. In fact, the law stipulated that all utility sales and purchases had to go through the PX and the CAISO. Power was purchased up to a day in advance, with shorter-term purchases made as little as 10 minutes before the electricity was to be sold. This arrangement was apparently believed to be sufficient for utilities to make necessary adjustments. Because the utilities had been required to sell what remained of their power-generating capacity and restricted from buying back that capacity, or any other capacity, under long-term contracts, they found themselves in a high-risk situation.

The Challenge

Because the market system was set up with controlled retail prices, the risk became a challenge for California. Economists have posited that with higher prices, supplies come forward, and part of the rationale for the restructured system was to elicit new supplies of electricity through the construction of new generating plants. Engineers and economists know, however, that even with higher prices, electric generating plants cannot be pushed beyond their capacity. In the short run, rising wholesale prices in California allowed the state to purchase additional electricity from western states connected through the power grid.

Opponents of deregulation claim that the process failed because it did not bring forward new supplies of electricity. As Figure 1 shows, however, there was a rapid surge in applications and the construction of new power plants. More new plant applications were submitted in 1998 than in any of the preceding 16 years.

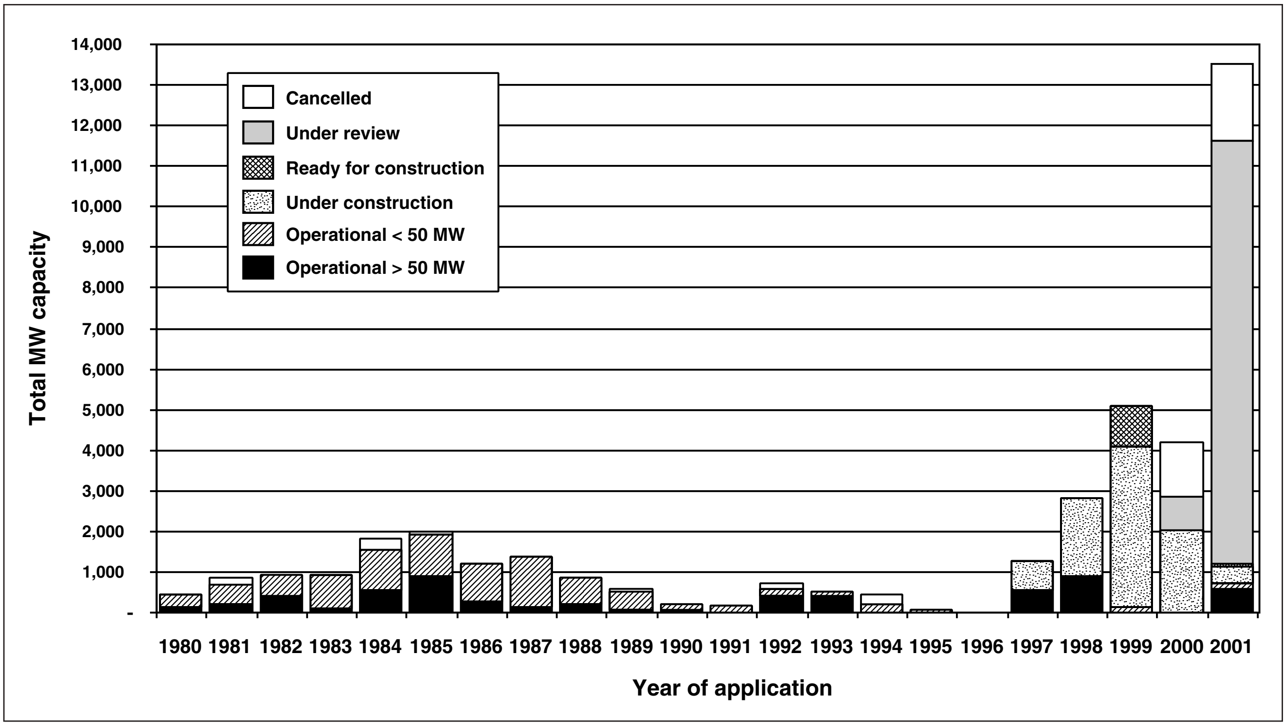

FIGURE 1 Applications for and construction of new power plants. Source: Sweeney, 2002.

And in 1999 and 2000, there were even more applications than in 1998.

New plants can be built, but construction takes time. In California's case, however, more than time was needed. The state also has a difficult and time-consuming process for licensing. Time has to be allowed for advocacy and input from affected parties, which not only delayed construction but also created uncertainties for utilities and generators as to whether they would actually realize benefits by installing new capacity. This uncertainty caused delays in the forward momentum of new generating plants.

Deregulation could not bring new plants on line instantly. Consider, for example, the Metcalf Energy Center in San Jose, which began to seek regulatory approval in 1999. Metcalf was still seeking approval until very recently, even after the major price spikes of 2001. It is ironic that CISCO Systems, Metcalf's neighbor and a member of an industry that relies on energy for communications and manufacturing, was a major opponent of construction because CISCO did not want a power plant near its manufacturing plant. Even environmental groups, such as the Sierra Club and the American Lung Association, had endorsed the construction.

A second claim of opponents of deregulation was that there was a sudden demand for electricity and that it surged in ways nobody had predicted. It is true that demand increased about 4 percent from 1999 to 2000, more than in previous years. But the demand was only slightly higher than projected and not out of the range of expectations. At the same time, however, there was a lack of rainfall in the Pacific Northwest and an increased demand for electricity in the Southwest. Thus, available imports to California were reduced by an average of more than 2,000 megawatts from 1999 to 2000.

The combination of a small delay in new plant construction, a slightly higher demand than projected, and a small reduction in imports in a system that was already operating close to the edge caused problems. Hydroelectric, nuclear generation, and newer, more efficient gas-fired facilities were already working at full capacity.

The result was a significant increase in demand for power from older, less efficient gas-fired plants, which have much higher heat rates (i.e., they use more natural gas per megawatt hour of electricity generated). Therefore, when there were no other options, the highest cost units of energy were introduced. In addition, the spike in the use of natural gas increased the demand on an aging system of natural-gas pipelines, which was also forced to operate near its transport capacity. Because no

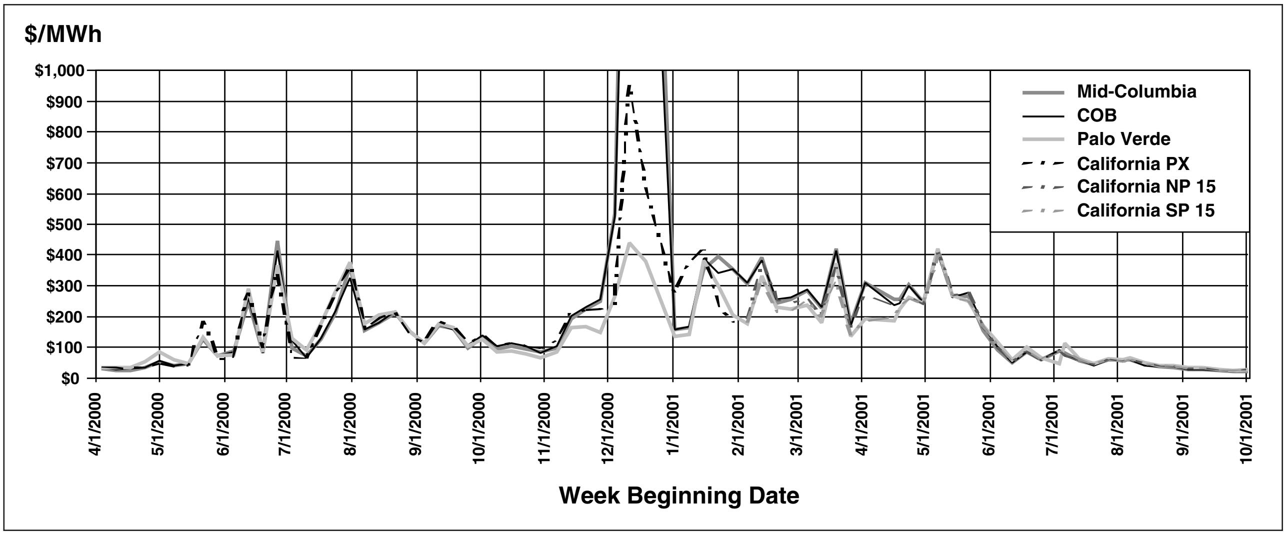

FIGURE 2 Spot power prices: average of high and low peak prices for several western markets. Source: *www.newsdata.com.*

substantial investment had been made to upgrade the pipeline infrastructure, the delivery of natural gas was constrained, which increased natural gas prices dramatically. Another reason generating capacity was limited that winter was that during the preceding summer the power-generating system had been operating at such high capacity that it was already near the breaking point. Many plants had to be shut down for repairs during the winter.

The Crisis

As of June 2000, these combined problems resulted in a serious challenge to California's energy system. Prices per megawatt hour in California, which were near $30 in April, rose to more than $100 by June 2000. By November, prices had increased to between $250 and $450. The first five months of 2001 were characterized by soaring wholesale prices, energy emergencies, and a small number of rolling blackouts. The pain was severe.

Although the electricity crisis was publicized as a California crisis, wholesale prices also soared throughout the entire Pacific Northwest and the Southwest. Similar, although less publicized, price spikes occurred in other states, but they responded differently. Figure 2 shows the wholesale prices for three non-California locations—just north of the California-Oregon border (COB), receipt points along the Columbia River (mid-Columbia), and the switchyard of the Palo Verde Nuclear Power Plant in Arizona (Palo Verde)—as well as California prices—original PX prices, prices in northern California (NP 15), and prices in southern California (SP 15). Non-California prices are shown with solid lines; California prices are shown with broken lines. As the figure shows, prices were almost identical in all of these areas except during December 2000, when California price controls kept wholesale prices below the COB and mid-Columbia prices, and early January 2001, when the financial risks associated with

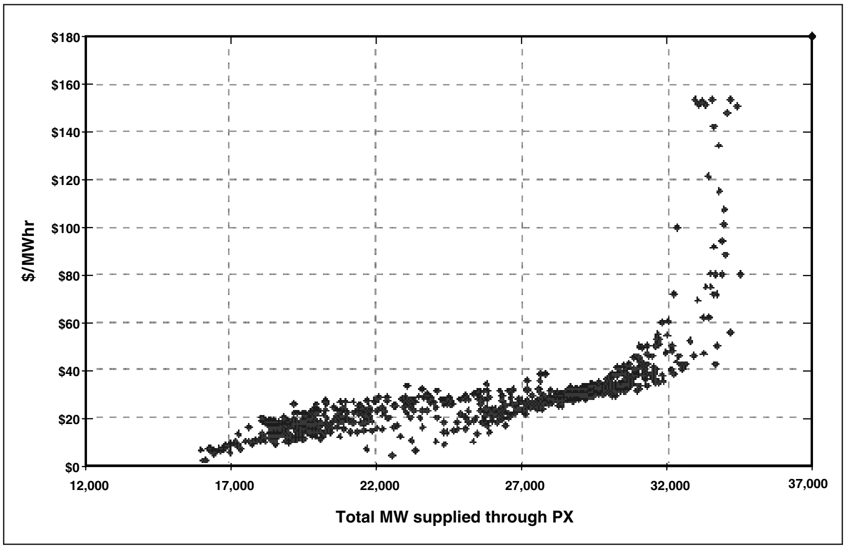

FIGURE 3 Total megawatts at one-hour intervals and prices per megawatt hour. Source: Sweeney, 2002.

the crisis pushed California prices somewhat higher than the others. The wholesale electricity price crisis affected the entire western United States through the interconnected distribution system.

As of June 2000, and perhaps as late as early 2001, if wholesale prices had been allowed to serve as price signals to consumers in California, which accounted for 40 percent of the western electricity use, the problem was still fixable. Higher retail prices would have encouraged rapid, broad-scale energy conservation, which would have been the key to placing downward pressure on the wholesale prices. But, California officials did not rise to the challenge and allow price signals to pass to the consumer, thus creating a crisis.

If the state had allowed retail prices to increase with wholesale prices, the wholesale price increases would have been much smaller. This point is illustrated Figures 3, 4, and 5. Figure 3 shows the market clearing wholesale price of electricity per megawatt hour on the PX as a function of the total megawatts demanded at one-hour intervals beginning in July 1999. When demand is well below capacity, even significant changes in demand have little influence on wholesale prices. As the figure shows, supply can be increased over a wide range without having much influence on price. Once demand exceeds capacity, however, prices rise sharply as the system puts the least efficient plants on line.

Figure 4 shows the supply and demand equilibrium under California's retail price control regime. With no price signals making their way to California consumers, demand was almost independent of wholesale prices. When wholesale prices rose, retail prices did not, and consequently, consumers were not motivated to reduce their use of electricity. Wholesale prices had to increase greatly to balance supply and demand, and that large price increase was the essence of the electricity crisis. A slightly larger increase in supply finds no equilibrium, resulting in what has been called rolling blackouts—real shortages in the system.

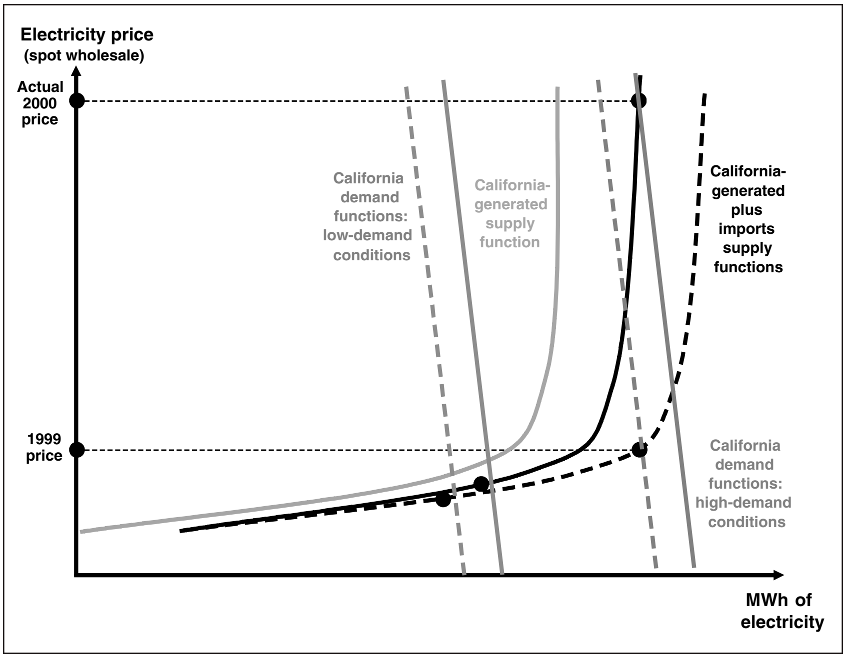

FIGURE 4 Supply and demand system with retail price controls. Source: Sweeney, 2002.

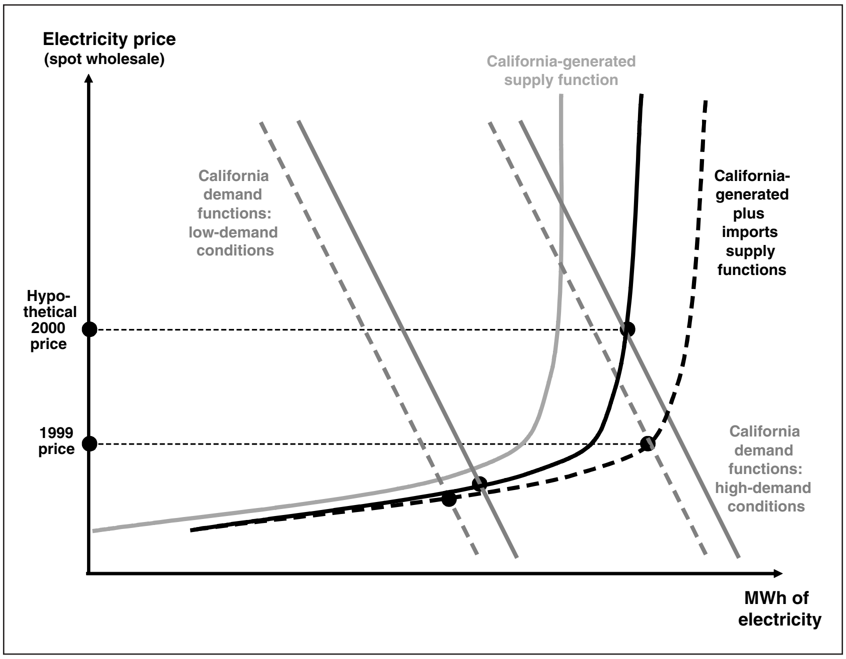

FIGURE 5 Supply and demand system with no price controls. Source: Sweeney, 2002.

Figure 5 shows a more sensible supply-demand system with no price controls and signals properly communicated between buyers and sellers. Wholesale price increases translate to retail price increases, which in turn motivate reductions in electricity demand. The net result is that wholesale price increases are limited. The time delay between the price signal and the market response was an important part of the market dynamics in California.

Rather than allowing prices to motivate reductions in demand, California state officials continued to assert the need for stronger wholesale price controls, which had been part of CAISO from its inception in 1998. These price controls were managed and controlled by the state. But, in December 2000, under orders of the Federal Energy Regulatory Commission (FERC), purchase price controls were replaced by a "soft cap" on wholesale markets. Under the "soft cap," bids higher than the cap could be accepted but had to be cost-justified. The FERC ordered the soft price cap to limit price changes while allowing cost-based price increases above the wholesale price-controlled levels. Thus, the soft cap did make it easier for CAISO to acquire out-of-market electricity and enabled California to avoid continuous rolling blackouts. But soft caps were generally ineffectual, and they encouraged gaming of the system by generators and marketers, for example, by exporting electricity from California and reimporting it at a higher price, consistent with prices outside California.

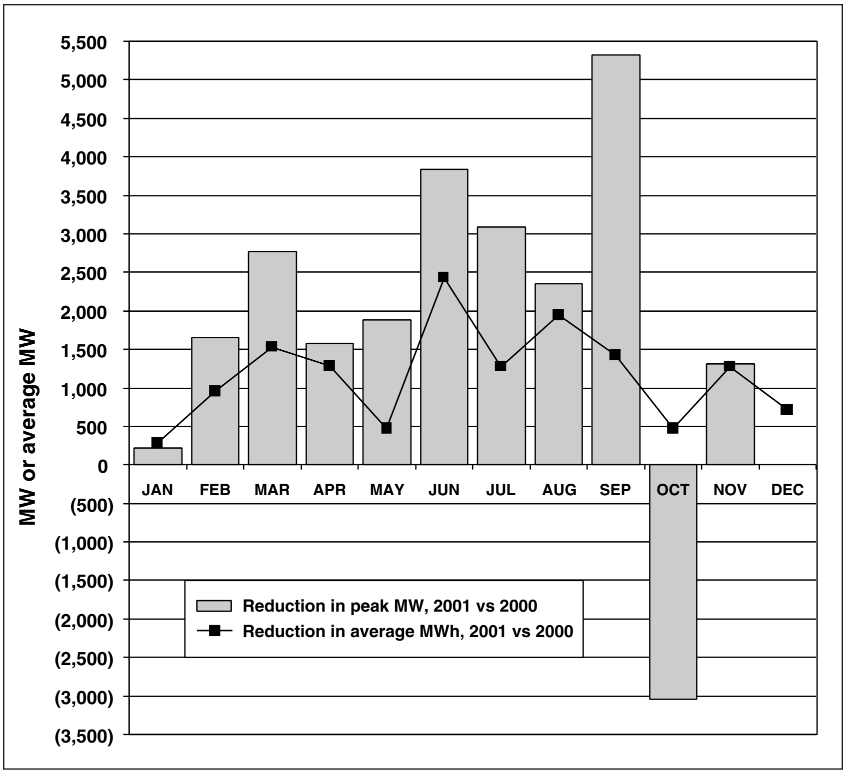

FIGURE 6 Reductions in electricity in 2001 and 2000. Source: Sweeney, 2002.

In fact, California experienced two crises—an electrical supply crisis and a financial crisis—creating a feedback loop that made matters worse. Inadequate supplies led directly to high wholesale prices, but California created the financial crisis for itself. With retail price controls, high wholesale prices, and utilities that had already sold off most of their generating assets, the utilities were forced to buy electricity from others. When the purchase price rose beyond the capped retail selling price, the point at which most retailers would stop selling the product, electric utilities were not allowed to stop under California's regulatory management.

The net result was that the financial assets and the borrowing power of the big electric utilities, PG&E and Southern California Edison (SCE), were completely drained and destroyed. With their monetary resources depleted, the utilities were no longer credit worthy, and generators would not sell them electricity. At that point, the state stepped in and took over as the sole buyer of electricity for the utilities. Unfortunately, state budgets are not unlimited; so the dual financial and electricity crises continued. Ultimately PG&E declared bankruptcy; SCE was on the verge of bankruptcy but eventually negotiated a settlement with the CPUC. PG&E remains in bankruptcy court; PG&E and the CPUC have proposed diametrically opposed plans for PG&E to emerge from bankruptcy.

California's financial crisis was the result of the state government's mismanagement of the electricity crisis. Most utilities in other states operate under a combination of long-term, medium-term, and short-term contracts to optimize their purchases. This is an appropriate financial arrangement for the electricity market because prices may spike, as happened in 2001. The CPUC however, did not allow long-term contracts. Therefore, the average cost to investor-owned utilities in California rose far more than the average cost to California municipal utilities or utilities in other states. More important, when the cost went up in other states, retail prices followed. Price signals in those states were communicating, although with a lag and attenuated by average cost pricing. Nevertheless, these utilities were able to collect enough revenue to pay for the power they bought and thus avoid a financial crisis.

One result of the financial crisis in California was that when the utilities ran out of money, they couldn't pay their electricity suppliers. Organizations that the California governor derided as "Texas utilities" (most of which were not utilities and were not based in Texas and several of which were public agencies from California, Oregon, and British Columbia) were able to keep producing despite delays in payment. But many small cogeneration plants, or qualifying utilities (QFs), which came into being under the Public Utility Regulatory Policies Act (PURPA), operate in a nearly hand-to-mouth way. When they were not paid, they were forced to shut down. In short, the initial supply crisis led to a financial crisis that led to a further reduction in supply that, in turn, led to higher prices.

Once the investor-owned utilities ran out of money and the PX was shut down, the state took over the purchase of electricity on behalf of the utilities. The financial crisis of the utilities then became a state financial crisis. Through August 31, 2001, the state had paid $10 billion for electricity, which was sold back to the utilities at the regulated price for about $3 billion. Thus, the state lost about $7 billion from the state budget. The "good news" was that California had a budget surplus of $8 billion, so the purchase "only" decimated the surplus.

Thus, the problem in California was not electricity deregulation; it was price regulation at the retail level and rigid regulation prohibiting long-term contracts at the wholesale level. It was an issue of gross mismanagement by the California governor and the CPUC.

As of June 2001, the seven-month California electricity crisis was over; wholesale prices had fallen to less than $50/MWh, demand had dropped, new generating plants were coming on line, and more new plants were in the pipeline. Figure 6 shows a drastic reduction in electricity use, some of which can be attributed to price increases at the retail level and some to demand-side management or other energy conservation programs. New generating plants have now come on line in California, although after the crisis was over. This new construction should ensure that the crisis will not recur in the near future. Figure 7 shows California's cumulative estimate of new capacity expected to come on line in the next three years. By December 2004, it is estimated that there will be 12,000 extra megawatts of new capacity. In 2002 alone, there will be 5,000 new megawatts. As a result of the new production coming into the system, there will be continuous downward pressure on prices.

The Blight

The electricity crisis was limited by circumstances, but the financial crisis continued. The mismanagement of the crisis resulted in financial obligations that now threaten to blight the California electricity system and its economy. Although the state experienced a short-term electricity crisis, the California governor made a decision to adopt long-term electricity purchase contracts to address the short-term problem. But under these long-term contracts, the state promised to pay prices roughly twice as high as the expected market prices. The total contractual production delivered as of January 2001, was 3,400 megawatts. But the contracts call for additional supply, peaking in January 2004 at 8,000 megawatts and continuing at that level until 2011. Some contracts go on for up to 20 years. The new contracts, which were signed early in 2001, were intended to deal with an energy crisis that was arguably already over by the time the first electricity was scheduled to be delivered. If all costs are added in, electricity prices will be about $100/MWh until January 2003; thereafter, they will drop to about $71/MWh. These prices will extend at least until 2011.

Mismanagement of the crisis left California with financial obligations that threaten to blight the state's economy.

The annual rate of expenditure will be about $4 billion a year for these contracts, which will also continue until 2011. Under the plan, these costs will be paid entirely by electricity consumers. The governor demanded that the contracts be renegotiated, but so far the renegotiations have primarily shortened the

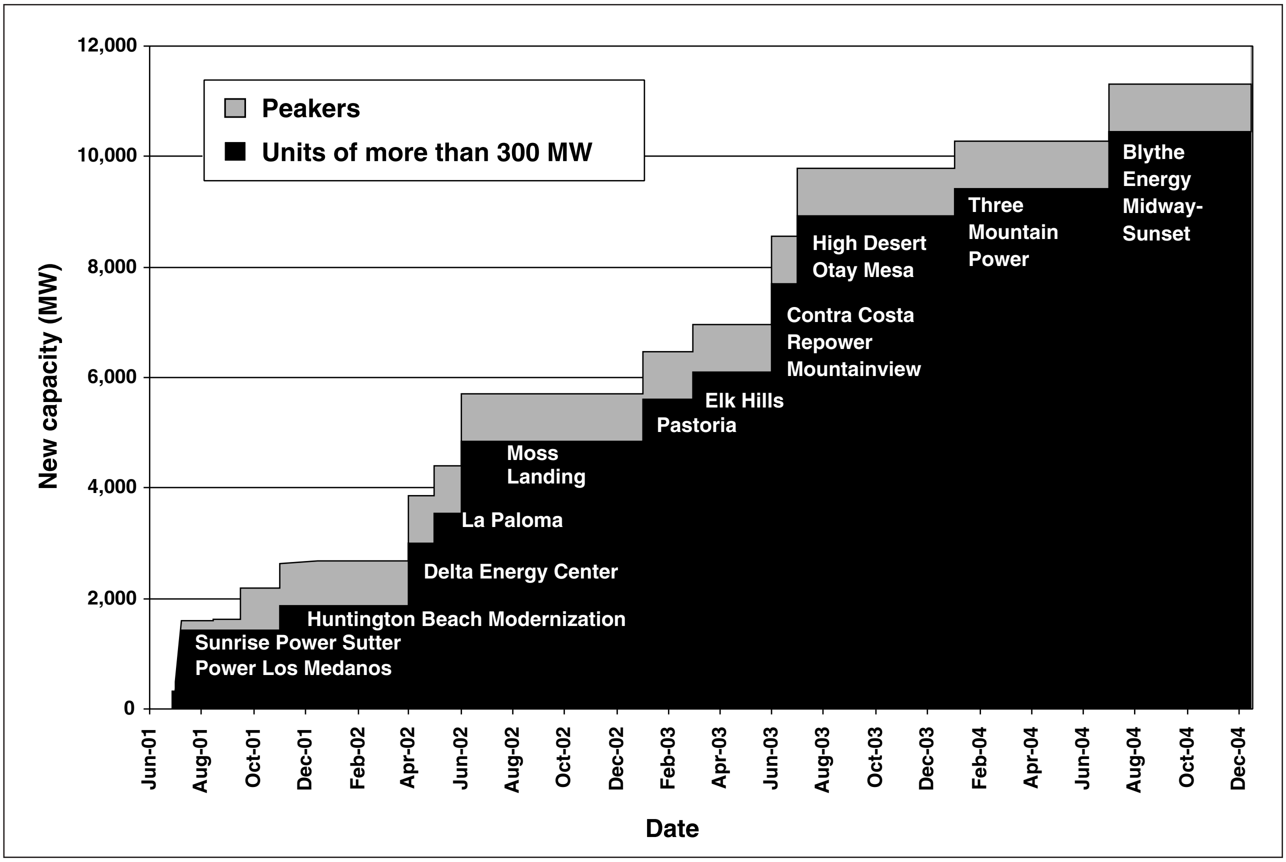

FIGURE 7 Cumulative estimate of new capacity. Source: Sweeney, 2002.

duration of the contracts without materially reducing the costs; in addition, the state has given up the legal right to challenge the generators for overcharging during the crisis.

The state plans to issue electricity revenue bonds to cover the costs of past electricity purchases. If the state issues $13 billion for the bonds, the rate payers would be charged an estimated cost of $1.2 billion per year paid over 15 years to repay this financial obligation. The bond payments and the payments for the long-term contracts would be added to retail electricity prices to be charged to consumers and companies in California. This additional cost creates a strong incentive for industries to bypass California's electricity market and contract directly with generators or invest in distributed generation and generate their own electricity. If companies made such a choice, the costs would be paid by somebody else. When the governor and the legislature realized that consumers were likely to have to bear these costs, California passed a law eliminating direct access, which made it illegal for industries to enter into direct contracts to buy electricity from generators thereby bypassing the financial consequences of the crisis. Thus, as of July 1, 2001, no new direct contracts are allowed between generators and users of electricity. In other words, California is blocking off retail competition to pay for its long-term contracts and state revenue bonds.

The Future

Despite the mistakes that have been made, some things can be done to improve California's prospects for the future. California should encourage private-sector investment and the development of new generating capacity to decrease the risk of shortfalls in supply. The system will also require better risk management because, in this integrated system, investments in transmission facilities and generating facilities will affect the rest of the system. The crisis is over for now, but there is a potential for future crises, particularly if state actions chill the climate for new construction and plants that have already been approved decide not to proceed.

The problems with the electrical infrastructure and the natural-gas pipeline and storage system must be addressed. Ideally, the electrical infrastructure of the western states could be interconnected with the infrastructure of the eastern states. This would have allowed California to export some of its problems, but a benefit/cost analysis may show that this solution is too expensive. California should carefully reassess its transmission infrastructure, including the infrastructure connecting northern and southern California.

Retail prices should reflect wholesale prices, either on average or through real-time pricing. This would give consumers incentives to respond by reducing their demand for electricity. The role of market power by generators in creating the electricity crisis is being debated. The system should be examined closely to ensure that it is working competitively.

The state should allow utilities to enter a broad range of contractual structures. An industry that works with a nonstorable commodity like electricity, which must be sold upon production, needs to have contract structures that manage risk. Ultimately, the system should be much less dependent on political decision making.

Lessons Learned

We can learn two major lessons from California's experience. First, we should not conclude that deregulation does not work and that it should be avoided in the rest of the country. Pennsylvania is a fine example of successful deregulation. In other parts of the world, deregulation also works well. England had some problems initially, but deregulation is working well now. New Zealand, Australia, and Chile are far ahead of the United States. The issue is not that deregulation does not work but that it should not be done the California way. In fact, deregulation can work very, very well.

Second, isolation of the supply side of the market from the demand side breeds disaster. Appropriate risk management and analysis are essential. Ultimately, any major restructuring of a system, whether it is a company, the military, or the electricity system, is bound to have problems in the beginning. The system must be monitored, and management must be flexible and quick enough to respond appropriately. Governors and legislatures need to act courageously and wisely and not solely for political expediency.

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A sound energy future will require restructuring of the industry, new technologies, environmental stewardship, and fuel diversity.

The Future of the U.S. Energy Industry

E. Linn Draper, Jr., is a member of the NAE and CEO of American Electric Power. This article is based on a presentation given at the Technical Session of the NAE Annual Meeting in October 2001.

E. Linn Draper, Jr.

This article about the future of the U.S. electric power system is based on my experience as CEO of American Electric Power (AEP), an investor-owned, multinational energy company with 4.9 million American customers. Most of us know the expression that nothing happens until somebody sells something. For electricity, the parallel truism is that nothing happens until somebody engineers something. A century or so ago, Edison, Tesla, Steinmetz, and others engineered practical advancements of an idea and got U.S. commercial electrification rolling. As they say, the rest is history. Electrification now heads the NAE's list of top 20 engineering achievements of the twentieth century. Not one other item on that list—from radio and TV to air conditioning, refrigeration, laser and fiber optics, and nuclear technologies—would exist as it does today, in most cases could not exist at all, without electrification.

In 1950, according to the U.S. Energy Information Administration (EIA), electricity accounted for 13.8 percent of the country's energy consumption. Fifty years later in 2000, it accounted for 41 percent of total energy usage. The EIA recently reviewed its estimates of growth in electricity demand between now and 2020 and revised its figures upward from 1.3 percent a year to 1.8 percent. The increase is based partly on the wider use of electricity-consuming hardware, including power electronics, AC-DC converters, and electrical storage devices.

In little more than a century, electricity has become an essential prime mover of our society and our economy. In the second electric century, the value of its capabilities will grow at a pace that would have boggled the minds of Edison, Tesla, and Steinmetz.

Intensified Security Attention

We have a tendency now to gauge events in our lives as before or after September 11. The attacks on that day presented no threat or general harm to the U.S. energy infrastructure, but they caused huge damage to the electric system of Consolidated Edison in lower Manhattan. The amazing speed with which Con Ed restored temporary service is a great credit to its emergency preparedness. George Friedman of STRATFOR, a global strategic forecasting firm, has suggested that the attacks were more than terrorist strikes. They were special operations planned to cause major disruptions to vital systems, in this case including the financial markets and air transport. As we move forward, protecting the electric and overall energy infrastructure—in its physical and cyber dimensions—must have a higher priority than ever before, in both the private and public sectors. At the same time, we must anticipate disruptions from a variety of causes and be prepared to respond appropriately. In this respect, we might look back at the Y2K "crisis" of a few years ago. No one knew at the time that the billions of dollars spent by energy companies on Y2K preparations would have a second payoff less than two years later. Those preparations, which were intended to prevent computer or terrorist disruptions in the transition to 2000, have given companies a significant leg up on the additional security that must now be considered.

Whither Restructuring?

On the political and policy fronts, before September 11, the state-by-state restructuring of the U.S. electric power industry that had been ongoing for a while had come down with a bad case of "Caliphobia." The California malady had substantially infected restructuring activities that were in various stages of progress in numerous other states and essentially immobilized those activities in a number of them. Is this a permanent immobilization? Even with the new uncertainties, my answer is no.

The lesson from California and other states is that you can restructure. California just got it wrong. I continue to believe that state-by-state restructuring of the electricity industry will ultimately be resurrected and will proceed. I say that because wholesale competition continues to grow, and many customers continue to want retail choices of their electricity suppliers. As Pat Wood, the new chairman of the Federal Energy Regulatory Commission (FERC), put it, "Power generation, power sales are not monopolies. Power delivery is."

Prior to September 11, there were any number of energy and environmental policy debates in the Congress and federal regulatory agencies that are largely or completely off the agenda for now. Some of the debates that have continued have been redirected to focus on energy security, U.S. energy independence, the reliability of infrastructure, energy delivery interconnectedness, redundancy, backup, and so forth. Other debates will undoubtedly resume.

The bottom line is that the policy and politics of energy, which were complex and complicated before September 11, are even more so now. Sorting out the policy implications of September 11 is going to be a long and difficult process.

Since September 11, the policy and politics of energy have become more complex—and more urgent.

Addressing Uncertainties with Technology

In a time of many uncertainties, however, the focus, if anything, is sharper on engineering, scientific, and technological responses. Many aspects of engineering the future of the electric power system have not been changed. Other aspects will be accelerated by the new realities. We know, for example, that restructuring of the electricity industry is changing the way decisions about technology choices are made. Industry restructuring is reorganizing the energy value chain, from the vertical integration of traditional electric utilities to the unbundling of the power generation, transmission, and distribution components. Companies are reinventing themselves to prepare for the future and the increasingly competitive marketplace.

In the past, the rate-making process allowed companies greater flexibility in making technology choices to meet society's needs. The economic models used in a regulated environment tended to favor capital-intensive investments that would result in lower power-generation costs, which, over a period of decades, often led to lower costs to society. Investment choices included coal-fired along with hydroelectric and nuclear power plants.

In a deregulated environment, there is more pressure to lower capital costs than to lower fuel costs.

In the highly competitive, restructured environment, the investor's time horizon is much shorter, and the least technical solutions are not always chosen. In this environment, technologies must be chosen to provide acceptable returns on investment without risking large amounts of capital for long periods of time. The economics of the deregulated environment place significantly more weight on lower capital costs than on lower fuel costs. The new model has favored investing in combustion turbines and combined-cycle power plants. In the past several years, gas turbines have captured more than 90 percent of the market for new power generation. In a competitive market that opens the transmission system to all participants, investments in technology benefit not only the owner but also competitors. Competitively oriented power plants dispatch electricity based on selling and contract requirements rather than on what might be optimal for the entire power grid or economical to consumers.

Issues related to power transmission, reliability, and adequacy, which were important before September 11, loom even larger in the face of heightened concerns about terrorism. These issues include: transmission congestion; the vulnerability of electric transmission lines and natural gas pipelines; and the security of key facilities, such as substations and control centers. The need for redundancy in the electricity delivery infrastructure and for stability-enhancing technologies is greater than ever. These technologies include: flexible AC transmission systems (FACTS); prompt spinning reserve; single-phase protection; faster relaying; automatic and remote-controlled load shedding; and real-time security analysis. FERC acknowledged these needs when it recently assured companies that they will be allowed to recover "prudently incurred" costs related to safeguards and new procedures.

Past underinvestment in transmission facilities has resulted in constraints at critical interfaces, created problems between regional grid systems, and is leading us toward large, independently operated regional transmission organizations (RTOs). Heightened concerns about reliability and security are further incentives for the formation of large regional transmission organizations with seamless interconnections between them.

The security of RTOs naturally will extend beyond their physical infrastructures to information technology and centralized transmission control. AEP supports the formation of for-profit independent transmission companies and has entered into a memorandum of understanding with PJM Interconnection, LLC, to become a member of the PJM RTO in the next year. In my judgment, large RTOs can effectively build in the reliability and security measures that will be imperative as we move forward.

Technology in the New Marketplace

Now I want to revisit the adage that nothing happens until somebody sells something. That could be the motto of the AEP (or any other) wholesale energy organization. In our strategies for the future, we have determined that selling is the principal growth engine of the company. The winning combination for success is an excellent trading and marketing team combined with an outstanding operations and technical group. An important given on the technical side is that the central electricity generation assets be efficient, optimized, and low cost. In other words, a successful energy company is a "big, efficient utility."

The companion piece to that traditional engineering is information technology that provides power plant operators with detailed information from the trading and marketing group about the expected prices for energy. The operators use that information to manage their generation assets effectively. Information and telecommunications technologies are coming together in support of both energy trading and asset management. The trading structure is constantly improving the availability of market information, trading details, and risk management. The key is to combine the effective application and advancement of traditional engineering concepts and modern information technology with a commercial mind set.

Sustaining Environmental Progress

Notwithstanding the present, crisis-related suspension of debates, more stringent multipollutant emissions constraints will be a reality for electricity-generating facilities within a decade. Coal-fired power plants will be hit first and hit hardest by the new regulations. This means that continuing innovations in cleaner, coal-burning power generation and the use of coal as a feedstock for other forms of energy, such as gases and liquids, will be critical.

Like many other companies, most (65 percent) of AEP's electricity-generating capacity is coal-based. "Keeping coal in the money" is, therefore, a given for us. The critical challenge facing us will be to retain the value of AEP's core capabilities and assets and, at the same time, improve environmental performance. And the key to effective environmental solutions is new technology. Last year, we created a special unit to support and invest in technologies that reduce emissions. We are moving forward with the installation of selective catalytic reduction technology in several of our plants to control nitrogen oxide emissions.

The current crisis may have temporarily sidetracked policy and regulatory debates about emissions control standards, but the industry is moving ahead with what needs to be done and will continue to do so. Smart companies will continue to shape their business strategies around environmental sustainability because it is the right thing to do and because it is good business.

Fuel Diversity

For strategic reasons, the U.S. government will continue to mount a strong push for energy independence. Therefore, a strategy for fuel diversity will be important to greater energy security in the power sector. An effective strategy will have to include a portfolio of generating fuels that maximizes the use of our most secure, indigenous resources. Of these, the supply of U.S. coal is the least vulnerable to disruption. The known recoverable supply of coal is estimated at 250 years' worth. Unlike natural gas and oil, coal can be transported by rail, water, truck, or pipeline. Even before September 11, we knew that coal would play a critical role in meeting future U.S. energy needs; that reality has been reinforced.

Nuclear power was being reevaluated before September 11, especially safety and waste disposal concerns. Now the security of nuclear plants has become a matter of equal, if not greater concern. I believe that nuclear plants have been made safer every year and that waste can be safely stored. New reactor designs, such as the pebble-bed modular reactor, may well have a place in our future generation mix, along with new light-water reactors of designs similar to today's 100-plus operating units.

I suggest that it is more important than ever for the U.S. Department of Energy to share in the cost and risk of new nuclear plants, as well as the cost and risk of bringing coal-based technologies, such as integrated gasification combined cycle plants, to commercial and competitive levels with currently available technologies. Coal gasification will reduce emissions and could produce two usable products, electricity, of course, and hydrogen, a clean fuel for fuel-cell generation. The hurdles are commercial, rather than technological. In addition, renewable energy technologies will be a small, but important, part of the overall generation mix and will continue to be advanced.

More stringent, multipollutant emissions constraints will become a reality in the next decade.

Distributed generation will play an important supplementary role, as a complement to the central generating station and to grid stabilization. Undoubtedly, the technologies and business models for distributed generation—including microturbines, innovative engines, fuel cells, and storage devices—will be commercialized in the next 10 years. A case in point is AEP Gas Power Systems, a joint venture company formed by AEP and G.A.S. Capital, Inc. This company will manufacture and market 1.2 megawatt gas turbine generators for use at remote sites, in cogeneration, in supplemental generation, and for backup applications.

The changing nature of the energy business will increasingly require new, more flexible sources of power generation to give industrial and especially commercial electricity customers a wider range of options.

A diversified fuel mix will be important, and we will have to tap every available resource to meet the energy demands of the twenty-first century, while continuing to improve the efficiency of energy use. And there is no getting around the critical role of coal or the technical innovations that using it will require to protect the environment.

Conclusion

The history of the electricity industry has been a proud chronicle of technological discoveries and innovations. Everything that has happened in this industry happened because somebody engineered something. To meet the challenges in this new century with its new electricity industry and new uncertainties and perils, engineers must become more involved in the policy making and political processes and remain aware of the social context of the engineering disciplines. Engineers and engineering will certainly make a huge contribution to a safer, more secure, and more prosperous nation and world.

NAE News and Notes

NAE Newsmakers

David K. Barton, retired executive vice president of ANRO Engineering, Inc., and independent consultant, will receive the IEEE **Dennis J. Picard Medal for Radar Technologies and Applications** on June 22 in Toronto, Canada. He is being honored for his contributions to radar system design and analysis, his radar reference texts, and his efforts to further the international exchange of radar technology information. The award consists of a gold medal, certificate, and cash prize.

Arthur E. Bergles, Clark and Crossan Professor of Engineering, Emeritus, Rensselaer Polytechnic Institute, received the **2001 Nusselt-Reynolds Prize** of the Assembly of International Conferences in Heat Transfer, Fluid Mechanics, and Thermodynamics. He was also elected to the Academy of Sciences and Arts, Slovenia, and named Honorary Professor at Beijing Polytechnic University, China.

Anil K. Chopra, Johnson Professor of Civil Engineering, University of California at Berkeley, was awarded the **George W. Housner Medal**. Dr. Chopra received the award for his fundamental contributions to structural dynamics and the understanding of how structures respond during earthquakes.

Don P. Giddens, current chair of the Wallace H. Coulter Department of Biomedical Engineering at Georgia Institute of Technology and Emory University, has been named **Dean of Georgia Tech's College of Engineering** effective July 1.

Michel T. Halbouty, chairman and chief executive officer, Michel T. Halbouty Energy Company, was inducted into the **Texas Science Hall of Fame**. Dr. Halbouty was recognized for his numerous contributions to the geosciences, including Gulf Coast salt dome prospecting and the discovery and use of oil and gas resources. In addition, he was awarded the **Legendary Geoscientist Award** by the American Geological Institute and American Geologic Foundation.

Herbert Kroemer, professor of electrical engineering and of materials, University of California, Santa Barbara, was awarded the **2002 IEEE Medal of Honor**. Dr. Kroemer was honored for his pioneering work in heterostructure-based transistors and light-emitting devices.

Tsuneo Nakahara, executive advisor to the chief executive officer, Sumitomo Electric Industries, Ltd., is the corecipient of the **2002 IEEE Eric E. Sumner Award**. Dr. Nakahara received the award for his pioneering contributions to the physical understanding, manufacturing, and deployment of optical-fiber communications systems.

Robert M. Nerem, Parker H. Petit Chair for Biomedical Engineering and Director of the Parker H. Petit Institute for Bioengineering and Bioscience, Georgia Institute of Technology, was awarded the **2001 Pierre Galletti Award** at the AIMBE Annual Meeting at the National Academy of Sciences in March. The Pierre Galletti Award was established in 1999 by the AIMBE Board of Directors to honor one of its founding members and past president, the late Pierre Galletti of Brown University. The award is presented to an individual in recognition of his/her contributions to public awareness of medical and biological engineering, and to the promotion of the national interest in science, engineering, and education.

Richard J. Robbins, president of The Robbins Group LLC, received the **2002 Washington Award** from the Western Society of Engineers for his role in the development of the modern tunnel boring machine.

Gavriel Salvendy, professor of industrial engineering, Purdue University, was appointed **Chair Professor and Head** of the newly established Department of Industrial Engineering, **Tsinghua University, China**. Dr. Salvendy will carry out his appointments at Purdue and Tsinghua concurrently.

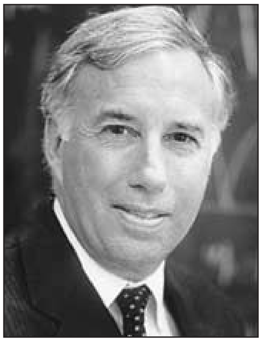
John J. Vithayathil, consultant, AC and DC Power Transmission, was awarded the **2002 IEEE Herman Halperin Electric Transmission and Distribution Award**. Dr. Vithayathil was recognized for his work in the development and implementation of systems that transmit large amounts of electricity, including his leadership in the development of the thyristor-controlled series capacitor (TCSC) system and the advancement of HVdc system technologies.

NAE Officers and Councillors Elected; Councillors Complete Service

George Fisher

Sheila Widnall

Elsa Garmire



Dan Mote

Siegfried Hecker

Robert Pritzker

The spring 2002 election of officers and councillors by the active members of the National Academy of Engineering (NAE) resulted in the reelection of two incumbent officers and one incumbent councillor and the election of two new councillors. In accordance with the Academy's bylaws, an additional councillor was subsequently elected by the NAE Council. All terms begin July 1, 2002. The fourth councillor position is elected subsequent to the members' election of councillors to ensure that the distribution of engineering disciplines on the Council is representative of the membership. For the 2002–2003 term, all 12 NAE sections will be represented.

George M.C. Fisher, retired chairman and chief executive officer, Eastman Kodak Company, will serve a second two-year term as NAE chair; and **Sheila E. Widnall**, institute professor, Massachusetts Institute of Technology, will serve a second four-year term as NAE vice president.

Robert A. Pritzker, president and chief executive officer, Colson Associates Inc., will serve a second three-year term as councillor. New councillors elected to three-year terms were **Elsa M. Garmire**, Sydney E. Junkins Professor of Engineering, Dartmouth College, and **Siegfried S. Hecker**, senior fellow, Los Alamos National Laboratory. At its May meeting, the Council elected **C. Dan Mote, Jr.**, president and Glenn Martin Institute Professor of Engineering, University of Maryland, to a three-year term.

The three councillors whose terms end on June 30, 2002, were recognized for distinguished service during a luncheon following the May Council meeting. The honorees were **Thomas E. Everhart**, president emeritus, California Institute of Technology, **Julia R. Weertman**, professor emerita, Northwestern University, and **Eugene Wong**, professor emeritus, University of California, Berkeley.

Draper and Gordon Prize Recipients Honored

Vince Vitto, George M.C. Fisher, Robert Langer, and Wm. A. Wulf.

NAE President **Wm. A. Wulf** hosted the NAE awards dinner and presentation ceremony on February 19 to honor the 2002 recipient of the Charles Stark Draper Prize and the inaugural Bernard M. Gordon Prize. The formal dinner was held at historic Union Station in Washington, D.C.

Robert Langer was awarded the **Charles Stark Draper Prize** for the development of biocompatible polymer technologies that control the release of medicine over time (from weeks to years). Langer's contributions have significantly advanced controlled drug delivery, a $20 billion industry in the United States alone. One of Langer's inventions, the first chemotherapy that can be delivered directly to the site of a brain tumor, broke a 20-year drought in FDA-approved treatments for brain cancer. Dr. Langer received a cash award of $500,000, a gold medallion, and a hand-scribed certificate.

One of a handful of active members of all three U.S. National Academies—National Academy of Sciences, National Academy of Engineering, and Institute of Medicine—Langer has written about 700 papers and holds some 400 patents, which are licensed or sublicensed to some 80 companies. He is known for helping students transfer their theses to the marketplace and for shepherding students into professorships. His protégés can be found at more than 80 universities around the world and have contributed substantially to chemical engineering and bioengineering education. "Bob Langer was chosen both for the substance of his contributions and because he is a role model," said NAE President Wm. A. Wulf. "The large number of companies his students have created is notable, effectively transferring the technology he has created into the private sector where it becomes available to all of us." (For Dr. Langer's remarks, see page 41).

The inaugural **Bernard M. Gordon Prize** was awarded to **Eli Fromm** for his educational leadership and reform of engineering education. Fromm is principal investigator of the Drexel E4 Project and principal investigator/director of the Gateway Engineering Coalition.

The Bernard M. Gordon Prize for Innovation in Engineering and Technology Education was established to encourage improvements in engineering and technology education relevant to the practice of engineering, the maintenance of a strong and diverse engineering workforce, the encouragement of innovation and inventiveness, and the promotion of technology development. The prize includes a cash prize of $500,000 (half of which goes to the institution), a gold medallion, and a hand-scribed certificate. In addition, Dr. Fromm will deliver a public lecture at the NAE Annual Meeting in October 2002.

"The intent of the prize is to identify experiments in teaching and learning that potentially benefit and impact engineering and technology

George M.C. Fisher, Bernard M. Gordon, Eli Fromm, and Wm. A. Wulf.

education," NAE President Wm. A. Wulf stated. "The focus is on innovations in curricular design, teaching methods, and technology-enabled learning. In today's world, an engineer must be comfortable working with product development teams consisting of marketers, financial people, and manufacturing specialists. The new environment requires an engineer to have strong communication skills in order to understand more about business and acquire a deeper understanding of the design process itself. Dr. Fromm and his colleagues were among the first and most influential in bringing these kinds of skills into the early part of the engineering curriculum." (For Dr. Fromm's remarks, see page 43).

The guest speakers at the awards dinner included **Vince Vitto**, president and CEO of the Charles Stark Draper Laboratory; **Dr. Maxine Savitz**, chair of the 2002 Draper Prize Selection Committee and former head of Technology/Partnerships at Honeywell, Inc.; **Dr. Mary L. Good**, chair of the 2002 Gordon Prize Selection Committee and managing member of Venture Capital Investors and professor at the University of Arkansas at Little Rock; and **Dr. George M.C. Fisher**, chair of the NAE Council and retired chair and CEO of Eastman Kodak Company.

Also present at the event was Gordon Prize benefactor **Bernard M. Gordon**, chairman and CEO of Analogic Corporation, who is known for his contributions to analog-to-digital conversion, tomography, and medical and other high-precision instrumentation. Dr. Gordon has more than 200 patents worldwide and was elected to the NAE in 1991.

The next Charles Stark Draper Prize will be awarded in February 2003. The next Bernard M. Gordon Prize will be awarded in February 2004. For additional information, please contact the NAE Awards Office at 202/334-1237 or *www.nae.edu/awards*.

How I Got Here

Robert Langer is a member of the NAE and the Kenneth J. Germeshausen Professor of Chemical and Biomedical Engineering at the Massachusetts Institute of Technology.

My engineering career had a rocky start. I was lucky to grow up in a loving family. My wonderful mother always did nice things for people, and my father used to play math games with me. When I was little, my parents bought me a Gilbert chemistry set. I enjoyed mixing chemical solutions together and watching them change color as the reactions took place. This is how I first became interested in science.

When I went to college at Cornell University, I didn't have a clear idea of what I wanted to do. In high school the only things I was good at were math and science, and the guidance counselor had told me I ought to become an engineer. At that point, however, I thought engineers ran railroad cars, and it wasn't clear to me how math and science would help with that. Nevertheless, I decided to go follow his advice, and, fortunately, I did well in chemistry my first year at Cornell—although I didn't do well in much else—and I decided to major in chemical engineering. But when I finished college, I still didn't have a clear idea of what I wanted to do.

One of the things that impressed me about MIT's chemical engineering department was that it was so diverse, ranging from biomedical engineering to polymer chemistry. I was very excited when I was accepted there. At MIT, I had the good fortune of working in Clark Colton's laboratory, where I met a couple of people who influenced me greatly—Bruce Hamilton, a fellow graduate student who gave me wonderful advice on how to finish my doctoral thesis, and Colin Gardner, a post-doc who taught me how to work experimentally in a lab. I also met Nick Peppas during my graduate days; he has been a wonderful friend, supporter, and advisor over the last 30 years.

When I finished at MIT, I still didn't have a clear idea of what I wanted to do with my life. It was 1974, and I received many offers for jobs at oil companies, which was where the action was in chemical engineering at that time. But I had a dream of improving people's health. Luckily, I ended up working with Dr. Judah Folkman, professor of surgery at Boston Children's Hospital and Harvard Medical School, who had a profound impact on my life. Dr. Folkman believed that almost anything was possible, and he set a terrific example for me. The projects I began working on in his lab involved polymer systems—plastics—that might be able to slowly release molecules. Many of these molecules were large or had a lot of electric charges associated with them, and no one had been able to develop a way to release them in a steady, controlled way. While I was working on this, I discovered that I could modify certain types of plastics and use them to release those molecules slowly.

Up to that point, my career was pretty straightforward. Then, in 1976, I was asked to give a talk on this work to an audience of distinguished polymer chemists and engineers. I was so nervous about it that I stopped working for about two weeks in advance so I could practice giving my talk over and over into a tape recorder. Finally, the day came to give this 20-minute talk. I got up, gave the talk, and I was pretty pleased with myself. I hadn't forgotten much of what I'd intended to say, and I hadn't stammered or stuttered much. I thought that all of the distinguished scientists in the audience, being nice people, would want to encourage me in my work. But, to my surprise, a number of them gathered around me and said they didn't believe anything I had said because those molecules couldn't possibly go through plastics.

That was my introduction to how scientists sometimes treat other scientists. It wasn't until several years later when some scientists began to repeat what we had done, that the question changed to how this could possibly happen! In fact, I spent a good part of my early career at MIT trying to understand the mechanism of release and answering that question.

Shortly after that talk, I began to apply for grant support. I wrote a number of grant applications, and the first nine were turned down. I wrote one grant to the National Institutes of Health for some cancer research and drug delivery research, and the reviews were very, very negative. Not only did NIH turn me down, but they also asked how I, "who knows nothing about biology and even less about oncology," could do this work.

When I finished my postdoctoral work, I applied for faculty positions in a number of chemical engineering departments, but I couldn't get a job because people felt that what I was doing wasn't engineering. So I ended up joining what was then the Nutrition and Food Science Department at MIT. The year after I got the position, the chairman of the department who had hired me left, and a number of senior faculty in the department told me I would not be rehired at the end of my three-year appointment. They advised me to start looking for another job.

So there I was. My grants had been turned down, people did not believe in my research, and I had little hope of even keeping my job—the lowest level academic position one could have. I was lucky, however, because, within a year or two, some people in the pharmaceutical industry started using some of the principles, and even some of the inventions, I had made. Things began to turn around, and I eventually did get promoted.

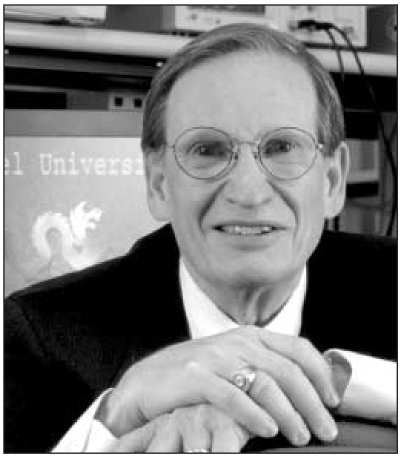
Around that time, I also had some ideas on how to create new polymers for medicine. I was very fortunate that I began to collaborate with Dr. Henry Brem, a very close friend, now the chief of neurosurgery at Johns Hopkins. We came up with a new way of using polymers to deliver drugs locally to treat tumors that is being used today to treat patients.

Also in the 1980s, I had the good fortune of working with Jay Vacanti, a transplant surgeon and a very good friend of mine. Jay and I came up with the idea that if you put cells on certain types of plastics, if you did it the right way, perhaps you could make new tissues. We are still working on this. We're not all the way there yet, but we are part of the way there. Tissue-engineered skin and cartilage are now available for certain problems, and several other engineered tissues are in clinical trials.

As the years went by, many graduate students and post-docs in our laboratory made other discoveries, many of which were met with skepticism. But I believe it's important to encourage students to follow their dreams. Today, more than 35 products based on our patents are either FDA approved or in clinical trials, and the principles we developed are being used by many pharmaceutical and medical device companies around the world. It's important to recognize that, even though I'm the one receiving this award, it's only through the work of hundreds of people in our laboratory over the years and thousands of people at companies that these kinds of products can be developed.

As I close this talk, I feel truly humble because I know of the incredible contributions of the people who have stood here before me. I am greatly honored that the National Academy of Engineering chose to award me this wonderful prize.

Changing the Paradigm for Undergraduate Engineering Education



Eli Fromm is a member of the NAE and the Roy A. Brothers University Professor at Drexel University.

From the 1950s through the 1980s, undergraduate engineering education became increasingly analytic and fragmented into a number of independent parts. At least they seemed independent to the student. In addition, there were strong pressures to keep adding new technical subject matter as well as pressures and national reports calling for more well-rounded graduates who could function in the socially interactive, communicative, and business climate of modern industry. Satisfying this broad range of demands within the traditional program structure was extremely difficult. Furthermore, attempts to address all of those demands resulted in a very intense curriculum that was devoid of early involvement in engineering and left little opportunity for intellectual enjoyment.

To address these issues, Drexel University began an experiment in 1988, initially designated "E^4", an acronym for an enhanced educational experience for engineering students. The program implemented a radical restructuring of the freshman and sophomore years. The success of E^4 then led to an extension of its concepts to address broader issues of the educational enterprise and the upper division of the curriculum and expansion to a group of cooperating institutions in what eventually became the Gateway Engineering Education Coalition.[1]

In the E^4 model and its extension, engineering is brought up front in a way much different from the traditional introduction to engineering survey course. Engineering is defined as the intellectual centerpiece from the beginning of the freshman year. Instead of the traditional sequential approach of math, science, and only then involvement in engineering studies, there is a vertical integration of engineering with the sciences, mathematics, humanities, and social sciences into a holistic experience that gives educators an opportunity to link the societal and historical perspective. Communication and organizational skills are embedded in the teaching of all subjects. Through teaming, the mathematical and scientific foundations are continually tied to their engineering applications in the classroom, as well as in the laboratory. For example, physics, mechanics, statics, dynamics, and calculus can be linked by a team from mechanical engineering, sciences, and mathematics under the topic "mathematical and scientific foundations of engineering." In a similar way, basic chemistry, chemical engineering, and the fundamentals of materials can be brought together in a program on the "structure, properties, and interaction of matter." The team approach develops the theoretical base around the engineering intellectual issue.

In the E^4 program, the emphasis is on experiential learning tied to classroom instruction. The experiential, or experimental, learning is first and foremost an engineering laboratory that teaches engineering principles from the first day of the freshman year; at the same time, learning is structured in a way that encourages the verification of scientific theories learned in the classroom. Thus, even in the experimental setting, the important supporting theoretical and essential base is identified with, and interwoven with, the professional discipline to which it is being applied. Design, the essence of the engineer's creative process, becomes a motivator and driver from the beginning of the freshman year and continues thereafter. Some independent work is required, but the emphasis is on student teamwork. Assignments involve engineering issues with open-ended solutions but defined deliverables and deadlines. Freshman design is only the beginning of the leadership development process. The positive self-image resulting from early successes piques the interest and increases the

[1] Partner institutions of the Gateway Engineering Education Coalition, headquartered at Drexel University, are Columbia University, Cooper Union, Drexel University, New Jersey Institute of Technology, Ohio State University, Polytechnic University, and University of South Carolina. The E^4 project and the Gateway Engineering Education Coalition have been supported, in part, by National Science Foundation awards USE-8854555, EEC-9109794, and EEC-9727413.

motivation of students even further, and their enthusiasm becomes catching. Thus, a curricular component is used to achieve multiple purposes—learning disciplinary content and developing human potential, such as organizational and leadership skills, as well as communications skills.

The strategies include transcending traditional departmental or college barriers, linking the fundamentals with their engineering purpose and application, and providing an environment in which engineering students readily identify with their chosen interests. The early involvement in teamed engineering activities brings a new level of enjoyment to an otherwise difficult and intense educational program. The concurrent aspects of the program in an engineering context results in a more time-efficient and content-efficient program in which faculty coaching and mentoring leads to the development of emerging engineering professionals. The program merges synthesis with analysis and abstract and societal-centered practices. It excites students, establishes a context for their studies, and gives them an opportunity to be creative and express a vision. Overall, this creates a student-friendly, broad intellectual foundation for which the school of engineering takes leadership responsibility.

The E^4 approach elicited a great deal of interest, and in 1992 a coalition of institutions was formed to go beyond the E^4 program. The Gateway Engineering Education Coalition, a collaborative of academic institutions selected for their diverse institutional structures and cultures, embraced the challenge of changing traditional engineering education from a program with a singular focus on course content to an inclusive curriculum that develops human resources; provides a broad experience founded on a multidisciplinary, integrated education; bridges educational research and development across institutional and collegiate boundaries; and changes the educational culture. The coalition has several goals:

- Extend the E^4 experience of the freshman and sophomore years to the broader institutions.
- Extend the concepts used in the first two years to the full engineering baccalaureate program.
- Address a range of issues (beyond program restructuring and curriculum), including professional development of students and faculty. For students, this includes teaming across institutional boundaries, understanding ethics in the context of engineering, developing communication skills, etc. For faculty, the new concept of professional development includes involvement in educational issues, such as recognizing the importance of different learning styles and experimenting with different educational methodologies.
- Press for programs that increase the number of underrepresented minorities who graduate from engineering programs by bringing the issue out in discussion among faculty and all stakeholders and by encouraging innovative initiatives.
- Employ leading technologies in the classroom when they can make the educational process more effective, and use leading technologies to enable students to conduct experiments from distant locations and across institutions.
- Develop an extensive assessment and accountability process that defines measurable outcomes and tracks them, at the same time using them as feedback to improve the system.
- Extend the experimental work of the coalition to additional institutions by linking coalition schools collectively and individually with other schools of engineering.

The E^4 principle of moving engineering up front (i.e., curricular inversion) created opportunities for new approaches in the upper division, such as cross-institutional student-faculty teams and the introduction of technologies just on the horizon. An example of the former is concurrent engineering, in which teams use video conferencing, fax, and e-mail to create designs across geographically dispersed institutions. This is analogous to the experience of design teams of a multilocation corporation collectively creating a new product design. Another example is an understanding of biotechnology that includes the underlying biologic concepts, as well as process control, materials, and the effects of scaling-up for mass production. Engineers must understand how to take basic work and make the technology transfer so the basic information becomes a factor in product development and the generation and creation of economic wealth, and, eventually, the betterment of the human condition.

Another example is a program that involves students across international boundaries in learning how to propose, manage, and bid on a solution to an engineering-based problem. An example of the introduction of technologies on the horizon is a team of faculty that uses educational modules to introduce cutting-edge engineering topics (on which they may be senior researchers) to undergraduate students. A set of modules can then be assembled from the available modules in a particular academic quarter or semester. Another exciting development is students being able to use remote control for experiments from any location that has online access.

Faculty are also examining educational methods—how we teach as well as what we teach—and using technologies to make the educational process more effective and rewarding. Student professional development includes not only communication, interpersonal, and team-building skills, but also ethical and societal considerations. All of these are built into an integrated program so they can be dealt with in context, rather than as independent units of a disjointed program. The engineering faculty have defined measurable objectives and outcomes, and student response data are collected, analyzed, and fed back for program improvement.

For more than a decade, we have witnessed the evolution of a significant and sustainable cultural change in engineering education. This is an exciting step that provides the engineering community an opportunity to take the lead in creating a new paradigm for undergraduate professional education.

Workshop on Diversity in the Engineering Workforce

On October 29–30, 2001, the National Academy of Engineering (NAE) Committee on Diversity in the Engineering Workforce brought together representatives of employers who have been recognized for their successful diversity programs to participate in a workshop entitled "Best Practices in Managing Diversity." The purpose of the workshop was to describe corporate programs that have successfully recruited, retained, and advanced women and underrepresented minorities in engineering careers and to discuss metrics by which to evaluate those programs. The workshop was focused primarily on personnel policies and programs for engineers employed in industry and consulting services.

The format of the workshop, which included plenary presentations followed by small group discussions, was designed to stimulate interaction among participants, as well as with the speakers. NAE president **Wm. A. Wulf** gave the keynote address, in which he stressed the importance of diversity and creativity in engineering problem solving. At the conclusion of the workshop, attendees were challenged to implement the best practices identified at the workshop in their own organizations.

In general, employers acknowledged that a corporate environment that allows all employees to succeed in the workplace contributes to corporate success. In addition to this general principle, discussions of why corporations focus on diversity in the engineering workforce repeatedly returned to four issues. First and foremost was the need for talented workers and the difficulty of finding enough qualified personnel. Workshop participants agreed that, although many corporations are being forced to reduce their workforces in response to current economic conditions, the long-term demand for engineers and other scientific and technical personnel will continue to increase. The United States cannot continue to rely on immigrants to fill engineering jobs in traditional and high-tech industries. A second related issue was the high cost to companies of employee turnover, both tangible costs for recruiting and training replacements and intangible costs associated with maintaining good relationships with clients and suppliers.

The third issue was the perceived competitive advantage of having a diverse workforce, which enables a company to provide better service to increasingly diverse clients and markets, a business imperative for companies that provide both engineering services and engineered products. Finally, engineers with different ethnic, gender, and cultural backgrounds bring a variety of life experiences to their work that can result in creative approaches to problem solving and design.

Proceedings of the workshop, *Diversity in Engineering: Managing the Workforce of the Future* (published by the National Academy Press and online at *http://www.nap.edu*), will be available in June 2002.

Report on Technological Literacy Released

The NAE successfully closed out its foundational project in technological literacy early this year. After more than two years of research and deliberation, the Committee on Technological Literacy released its report, *Technically Speaking: Why All Americans Need to Know More about Technology*, at a one-day symposium in January 2002 at the National Academies Building. More than 200 people attended. William Hanson, deputy secretary at the U.S. Department of Education, delivered the keynote address. Other speakers were Carl Kohrt, CEO of Battelle Memorial Institute, Rep. Rush Holt (D-N.J.), and Alan Friedman, director of the New York Hall of Science.

In the report, the committee makes the case for a concerted effort in the United States—through formal and informal education—to boost technological literacy. The report defines technology and technological literacy, describes the benefits of technological literacy, describes the current political, economic, and social context for technological literacy, and surveys past and current activities that contribute to technological literacy. The committee offers 11 recommendations in four areas: (1) strengthening the presence of technology in formal and informal education; (2) developing the research base; (3) enhancing informed decision making; and (4) rewarding teaching excellence and educational innovation. Copies of the report can be ordered from the National Academy Press, 2101 Constitution Avenue, N.W., Lockbox 285, Washington, DC 20055, by phone at (800) 624-6242, or online at *www.nap.edu*. A companion website to the report includes a web-friendly version of the report, as well as extensive lists of links and other resources. To visit the site, go to *www.nae.edu/techlit*.

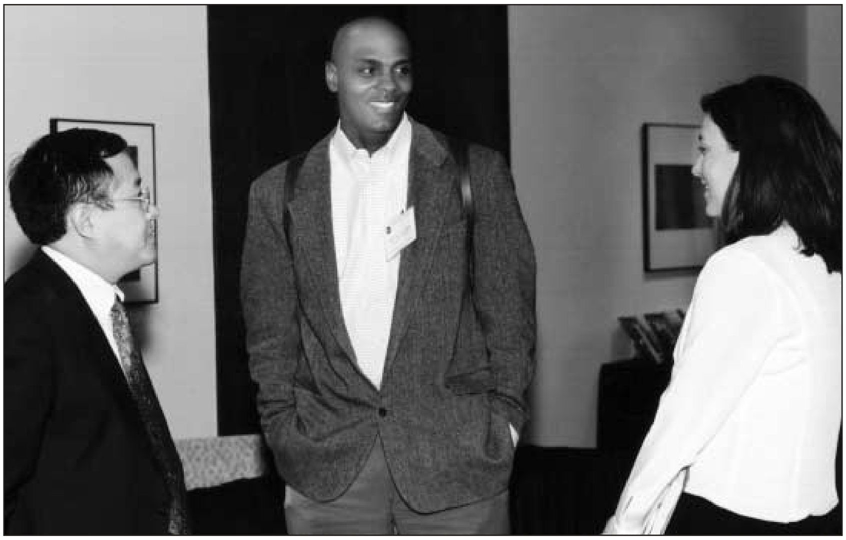
In March 2002, the Program on Technological Literacy received funding from the National Science Foundation for a follow-on project on the feasibility of measuring technological literacy among students, teachers, and the public in the United States. The project will be conducted in collaboration with the Board on Testing and Assessment, part of the National Research Council. For more information, contact Greg Pearson (202/334-2282; gpearson@nae.edu).

Seventh U.S. Frontiers of Engineering Symposium

Rick Kjeldsen (IBM), Bernhardt Trout (MIT), and Ike Chuang (MIT) examine a mini-unmanned air vehicle.

Micromechanical flyers, dynamic planning and control of civil infrastructure systems, the design of future wireless systems, and reengineering the paralyzed nervous system were some of the exciting topics covered at NAE's seventh Frontiers of Engineering Symposium, held March 1–3 at the Beckman Center in Irvine, California. (The symposium was originally scheduled for September but was rescheduled after the events of September 11).

Approximately 85 engineers attended the meeting on leading-edge engineering research and technical work. In a session called "Flight at the Leading Edge," participants were treated to a demonstration of a miniature, unmanned



Zhuomin Zhang (U. of Florida), Garrick Louis (U. of Virginia), and Rachel Davidson (Cornell) exchange views.

air vehicle (mini-UAV) that could be used for law enforcement, traffic monitoring, air pollution control, farming, fire spotting, power line inspection, search and rescue, and weather monitoring. In addition, two excellent talks were given on next-generation jet propulsion and micromechanical flyers. Speakers in the "Civil Systems" session—with presentations on dynamic planning and control of civil infrastructure systems, decision-making under uncertainty, and interdependencies in civil infrastructure systems—amply demonstrated the complexity and inherently interdisciplinary nature of maintaining communications and information, power, waste disposal, and transportation systems. The "Wireless Communications" session covered design challenges for future wireless systems, service architecture for emerging wireless networks, and wireless integrated network sensors. The symposium concluded with a session called "Technology and the Human Body" that covered three areas in which extraordinary breakthroughs related to health care are being made: (1) modeling and simulation of the human body to improve our understanding of diseases; (2) electronic devices that enable mobility in paralyzed patients; and (3) tissue engineering, including microfabrication techniques and cellular interactions. A breakout session on the afternoon of the second day provided an opportunity for participants to share their visions of the future, discuss the enabling technologies needed to realize them, and identify the implications for engineering education.

A high point of the meeting was the dinner speech given on the first evening of the symposium. This year's speaker, **Nicholas Donofrio**, senior vice president and group executive, Technology and Manufacturing, IBM Corporation, spoke about technology innovation and the importance of a diverse, interdisciplinary engineering workforce. NAE member **Michael Corradini**, chair, Engineering Physics Department and professor of nuclear engineering and engineering physics at the University of Wisconsin, Madison, chaired the organizing committee and the symposium. NAE member **Albert Pisano**, Fanuc Chair of Mechanical Systems at the University of California, Berkeley, also served on the organizing committee.

Funding for the symposium was provided by the Defense Advanced Research Projects Agency, the U.S. Department of Defense (DDR&E-Research), the National Aeronautics and Space Administration, Microsoft Corporation, United Technologies Corporation, and

Peter Lorraine (GE) asks a question of one of the speakers.

Cummins Engine Company.

In fall 2002, NAE will publish a volume containing extended summaries of the symposium presentations. An organizing committee, chaired once again by Michael Corradini, is planning the next meeting, which will be held September 19–21, 2002, at the Beckman Center in Irvine, California.

For more information about the symposium series or to nominate an outstanding engineer to participate in the September 2002 meeting, contact Janet Hunziker at the NAE Program Office at (202) 334-1571 or by e-mail at jhunziker@nae.edu.

Foreign Secretary's Report

Harold K. Forsen

NAE members have once again elected excellent foreign associates to our academy, and we all look forward to meeting them at our annual meeting in October. Foreign associates, whose credentials are comparable to those of regular members but who are not U.S. citizens, provide contacts with their countries of citizenship we might not otherwise have. For this and other reasons, I have advocated that more of these outstanding individuals be nominated and elected to the NAE each year. In February, the Membership Policy Committee supported this recommendation, and the NAE Council approved it. Therefore, in the 2003 election, the number of foreign associates elected will increase to 12 percent of the number of members elected, an increase of 2 percent. I personally applaud this cautious first step, and hope that you will nominate more deserving candidates. Assuming that the pool of nominees increases, the Council may consider a further increase in the future.

Whenever the opportunity arises, the Academy provides a "regional meeting" for foreign associates, visiting members, and members living overseas. This year, through the good offices of foreign associate Dr. Wolfgang Schmidt, DaimlerChrysler will host a regional meeting in Stuttgart, Germany, on August 28 and 29. Foreign associates have already been notified, and information will be mailed to members in the area soon. The meeting in Stuttgart will follow a CAETS meeting in Prague that will be attended by several representatives of NAE. We look forward to seeing all of you who live in the area.

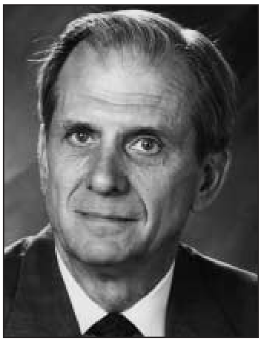
The Japan-America Frontiers of Engineering (JAFOE) Symposium, which was originally scheduled for November 29–December 1, 2001, in Irvine, California, was cancelled at that time because of Japanese concerns over travel to the United States. The symposium has been rescheduled for October 24–26, 2002, with the same program and participants, although it will be held in Tokyo instead of in Irvine, California. The topics will be bioengineering, the synthesis and applications of nanomaterials, pervasive computing, and sustainable manufacturing. The U.S. cochair for this activity is NAE member, **Dr. Robert Wagoner**, Ohio State University.

On May 16–18, 2002, NAE will host the fifth German-American Frontiers of Engineering (GAFOE) Symposium at the National Academies Building in Washington, D.C. Sixty engineers from Germany and the United States will hear presentations and participate in discussions on sustainable energy futures, tools for biomedical engineering, urban engineering, and intelligent transportation systems. The U.S. cochair for the GAFOE symposium is NAE member, **Dr. Sangtae Kim**, Lilly Research Laboratories.

H K Forsen

Harold K. Forsen
Foreign Secretary

Home Secretary's Report



W. Dale Compton

Dear Colleagues:

The success of our academy depends heavily on the many volunteers who participate in NAE committees. For this we are very grateful. I especially want to acknowledge the efforts of the 13 peer committees working on the nomination process for the 2003 election. A special thanks goes to all of the members who have nominated or served as references for nominees.

In addition to standing committees, occasional ad hoc committees, and special study committees created by the Program Office, several important positions in each NAE section must be filled through elections. These include section officers and members to serve on the NAE committee that nominates candidates for NAE officers and the Council. Another important function of each section is the selection of a liaison to the NRC.

Some section chairs have had difficulty finding members willing to serve either on the nominating committee or as NRC liaisons. I encourage members who are willing to serve to inform their section chairs of their interest. Each section has its own mechanisms for making these selections, and section members can, and should, participate in establishing the selection process.

Again, thanks for your past efforts and for your continuing participation in NAE activities.

W. Dale Compton
Home Secretary

Raphael Perl Joins the NAE as Fellow

Raphael Perl

Raphael Perl joined the NAE in January when he began a year-long fellowship with the Program Office. He will be involved in projects designed to bring science and technology to bear on counterterrorism and will be study director for the NAE Committee on Combating Terrorism: Prioritizing Vulnerabilities and Developing Mitigation Strategies.

Prior to his arrival to the NAE, Dr. Perl was senior policy analyst for terrorism with the Congressional Research Service of the Library of Congress. He is a graduate of Georgetown University Foreign Service and Law Schools, a retired Army Reserve Lieutenant Colonel and veteran of Desert Storm, and a graduate of the Army's JFK Special Warfare Center, the Air Force Special Operations Warfare Center, and the National War College. Dr. Perl is a member of the National Academy of Sciences Committee on Confronting Terrorism in Russia, and a regular speaker at academic institutions and governmental policy forums. He has also testified before Congress on terrorism policy issues.

Dr. Perl's numerous congressional and academic publications include *Terrorism, the Future, and U.S. Foreign Policy* (Congressional Research Service, 2002), *Terrorism—Looking Ahead: Issues and Options for Congress* (a report prepared for the Permanent Select Committee on Intelligence, 1996), and "Terrorism, the Media, and the Twenty-First Century: Perspectives, Trends and Options for Policy Makers" (*Journal of Low Intensity Conflict and Law Enforcement.*)

Karen Spaulding Joins NAE as Director of Membership

Karen Spaulding

In February 2002, Karen Spaulding took over as the director of the NAE membership office. Karen recently returned to the Washington area after five years in Denver, Colorado. She has more than 15 years of experience working with scientific and professional organizations, including the American Geophysical Union, the American Institute of Professional Geologists, and the Association for Women Geoscientists. In previous positions, she focused on developing and maintaining membership databases and managing administrative functions, facilities, and new building construction. She received a B.B.A. in finance from the University of Oklahoma, an M.B.A. from the University of Tulsa, and an M.S. in geology from the University of Oklahoma.

In Memoriam

JOHN A. BLUME, 92, consultant and retired chairman, John A. Blume & Associates, died on March 1, 2002. Dr. Blume was elected to the NAE in 1969 for pioneering work in the development and application of new design concepts and the analysis of the response of buildings and structures to earthquakes.

SOL BURSTEIN, 79, retired vice chairman, Wisconsin Electric Power Company, died on January 28, 2002. Dr. Burstein was elected to the NAE in 1985 for his technical leadership in the design, construction, and operation of pioneering commercial nuclear power plants.

GEORGE F. CARRIER, 83, T. Jefferson Coolidge Professor of Applied Mathematics (emeritus), Division of Applied Sciences, Harvard University, died on March 8, 2002. Dr. Carrier was elected to the NAE in 1974 for his leadership in the development and application of mathematical methods for the solution of engineering and geophysical problems.

WILLIAM F. CASSIDY, 93, retired Lt. General, U.S. Army Corps of Engineers, died on March 31, 2002. Lt. Gen. Cassidy was elected to the NAE in 1967 for the design and construction of military and water resource facilities.

FREDERICK J. CLARKE, 86, retired Lt. General, U.S. Department of the Army, died on February 4, 2002. Lt. Gen. Clarke was elected to the NAE in 1973 for contributions to the management of large-scale military and civilian programs in the field of civil engineering.

SATISH DHAWAN, 81, member, Space Commission, Government of India, died on January 3, 2002. Professor Dhawan was elected to the NAE as a foreign associate in 1978 for his leadership in aerospace research and education and his management of space applications and development programs.

FRANK R. FARMER, 86, retired visiting professor, University of Bradford, died June 10, 2001. Mr. Farmer was elected to the NAE in 1980 for the initiation and development of probabilistic techniques for the quantification of nuclear and industrial safety.

EUGENE C. FIGG, JR., 65, president and chief executive officer, Figg Engineering Group, died on March 20, 2002. Mr. Figg was elected to the NAE in 2001 for leadership in architectural excellence, structural innovation, and efficient construction of major bridges.

WILLIAM A. GOLOMSKI, 77, president, W.A. Golomski & Associates, died on February 17, 2002. Mr. Golomski was elected to the NAE in 1996 for contributions to the integration of customer-centered quality and engineering design.

HOWARD L. HARTMAN, 77, Drummond Chair of Mining Engineering and professor emeritus, University of Alabama, and retired consulting mining engineer, died on January 12, 2002. Dr. Hartman was elected to the NAE in 1994 for the design, codification, and practice of mine ventilation and air conditioning systems.

F. KENNETH IVERSON, 76, chairman, Nucor Corporation, died on April 14, 2002. Mr. Iverson was elected to the NAE in 1994 for the development of the mini-mill concept in steelmaking, which revitalized the American steel industry.

JOSEPH W. JOHNSON, 93, retired professor emeritus of hydraulic engineering, University of California, Berkeley, died on April 11, 2002. Mr. Johnson was elected to the NAE in 1976 for leadership in the field of coastal engineering.

ALFRED A.H. KEIL, 88, professor emeritus, Massachusetts Institute of Technology, died on January 9, 2002. Dr. Keil was elected to the NAE in 1966 for research on ship structures and explosions.

THOMAS J. KELLY, 72, retired president, Grumman Space Station Integration Division, and consultant, died on March 23, 2002. Mr. Kelly was elected to the NAE in 1991 for leadership in the design, development, and supervision of the construction of the Apollo Lunar Module.

MILES C. LEVERETT, 90, retired consultant, died on March 27, 2001. Dr. Leverett was elected to the NAE in 1984 for his pioneering contributions to nuclear reactor designs and his many contributions to safety in the nuclear industry.

JOHN R. PIERCE, 92, visiting professor of music (emeritus), Stanford University, died on April 2, 2002. Dr. Pierce was elected to the NAE in 1974 for his expertise in electronics engineering and satellite communications.

ALVIN RADKOWSKY, 86, chief scientist, Radkowsky Thorium Power Corporation, died on February 17, 2002. Dr. Radkowsky was elected to the NAE in 1991 for his seminal contributions and innovations in the development of nuclear power.

WALTER A. ROSENBLITH, 88, institute professor (emeritus), Massachusetts Institute of Technology, died on May 1, 2002. Professor Rosenblith was elected to the NAE in 1973 for his contributions and leadership in communications biophysics and the development of biomedical engineering.

MASSOUD T. SIMNAD, 81, adjunct professor of materials science and engineering, Nuclear Energy and Energy Technologies, University of California, San Diego, died on December 15, 2001. Dr. Simnad was elected to the NAE in 1995 for the development of materials and fuels for advanced nuclear energy systems and for interdisciplinary activities bridging materials science and energy technologies.

HAROLD A. THOMAS, JR., 88, Gordon McKay Professor of Civil and Sanitary Engineering (emeritus), Harvard University, died on March 26, 2002. Dr. Thomas was elected to the NAE in 1976 for making the field of civil engineering more responsive to human needs by incorporating statistics, economics, demography, and public policy.

PHILLIP A. THOMPSON, 72, professor emeritus, Rensselaer Polytechnic Institute, died on March 23, 2001. Dr. Thompson was elected to the NAE in 1989 for his contributions to the understanding of the dynamic behavior of nonideal fluids and for the discovery of liquefaction shock waves.

MONTE C. THRODAHL, 82, retired senior vice president, Monsanto Company, died on December 17, 2001. Mr. Throdahl was elected to the NAE in 1980 for his study of the relationship between regulation and innovation and his pioneering work in innovative industry-university interactions.

Preview of the 2002 Annual Meeting

Hotel rooms are available at a reduced rate until September 9, 2002, or until the hotels are fully booked. Please use the Meeting Code listed below when making your reservation. Taxes and parking charges are not included in price.

J.W. Marriott
1331 Pennsylvania Avenue, N.W.

Reservations:	202/393-2000 800/228-9290
Meeting Code:	NAE 2002 Annual Meeting
Rates:	$195.00 (single/double)

The J.W. Marriott has three restaurants, a health spa, an indoor pool, and valet parking. It is located one mile from the National Academies Building.

State Plaza
2117 E Street, N.W.

Reservations:	202/861-8200 800/424-2859
Meeting Code:	6670
Rates:	Stateroom Suites $129.00 (single/double) Plaza Suites $159.00 (single/double)

The State Plaza, three blocks from the National Academies Building, features a restaurant, an exercise room, and limited parking.

Preliminary Agenda

A continental breakfast and lunch will be provided on Monday and Tuesday. A guest program is being planned.

Friday, October 4

5:00–9:00	NAE Council meeting

Saturday, October 5

8:00–3:00	NAE Council meeting
8:00–5:00	Peer committee meetings Special events for NAE Class of 2002
10:00–4:30	Class 2002 registration
12:00–1:00	Lunch with Council
1:00–2:30	Introduction to the Academies
2:30–3:00	Break
3:00–4:30	Introduction to the NAE
7:00–9:30	NAE Council reception/dinner for Class of 2002 (black tie)

Sunday, October 6

10:30–12:00	Brunch
10:30–11:30	Estate Planning Seminar
12:00–1:30	Induction ceremony
1:30–2:00	Break (Class of 2002 photo)
2:00–2:40	Awards program
2:40–3:40	Lillian M. Gilbreth lecture
3:40–4:15	Break
4:15–5:00	Gordon prize recipient lecture
5:15–6:30	Reception

Monday, October 7

7:00–8:30	Foreign Secretary breakfast (by invitation)
7:00–8:30	Home Secretary breakfast (by invitation)
7:00–8:30	Continental breakfast
8:30–9:30	Business session
9:30–12:30	Legacies and Opportunities Science and Engineering in the 21st Century: A Symposium Honoring H. Guyford Stever
12:30–1:30	Lunch
2:00–5:00	Section meetings at new Academies Building
7:00–12:00	Reception/dinner dance (J.W. Marriott) with entertainment by Mark Russell

Tuesday, October 8

7:30–8:30	Continental breakfast
7:00–8:15	NAE section liaisons meeting
8:30–4:30	Technical Symposium Computing Meets the Physical World
4:30–5:30	Reception

Calendar of Meetings and Events

31 May	Congressional Luncheon
11 June	Governing Board Executive Committee
18 June	1st Charles Stark Draper Prize Committee Meeting
10–11 July	Forum on Diversity in the Engineering Workforce
12 July	Congressional Luncheon
16 July	Governing Board Executive Committee
25 July	1st Fritz J. and Dolores H. Russ Prize Committee Meeting
6 August	New Council Member Orientation Woods Hole, Massachusetts
7–8 August	NAE Council Meeting Woods Hole, Massachusetts
9–10 August	NRC Governing Board Woods Hole, Massachusetts
25–27 August	CAETS Council Meeting Prague, Czech Republic
28–29 August	NAE Foreign Associates Meeting Stuttgart, Germany
3–4 September	Engineering of 2020 Scenario Development Woods Hole, Massachusetts
10 September	Governing Board Executive Committee
19–21 September	U.S. Frontiers of Engineering Irvine, California
25 September	2nd Charles Stark Draper Prize Committee Meeting
4 October	Finance and Budget Committee Meeting NAE Council Meeting and Working Dinner
5 October	NAE Council Meeting Committee on Membership Peer Committee Meetings
6–8 October	NAE Annual Meeting
9 October	Governing Board Executive Committee
24 October	2nd Fritz J. and Dolores H. Russ Prize Committee Meeting
24–26 October	Japan America Frontiers of Engineering Tokyo, Japan
12 November	Governing Board Executive Committee
12–13 November	NRC Governing Board
15–16 November	NAE/NINCH Meeting
6 December	Committee on Membership Dinner Meeting
7 December	Committee on Membership Meeting
10 December	Governing Board Executive Committee

All meetings are held in the National Academies Building, Washington, D.C., unless otherwise noted.

National Research Council Update

National Transportation Air Quality Program Benefits Local Areas

A recent report by the Transportation Research Board recommends that Congress continue its surface-transportation program that funds projects to reduce traffic congestion and pollution in areas that must comply with national air quality standards. The study was sponsored by the Federal Highway Administration of the U.S. Department of Transportation.

The report also recommends that the U.S. Department of Transportation (DOT) Mitigation and Air Quality Improvement Program, which was established in 1991, be modified to reflect changes in motor vehicle travel and emissions over the past decade, such as “cleaner” vehicles and fuels and a better understanding of the adverse health effects of pollutants. Other recommendations were: a continued high priority for improvements in air quality; more involvement by state and local air quality agencies in reviewing proposed projects; and the allocation of program funds to encourage better assessments of funded projects. The focus of the program should be expanded beyond its current focus on regions with ozone and carbon monoxide pollution to include all pollutants regulated under the Clean Air Act.

NAE members on the study committee were: **Martin Wachs** (chair), University of California, Berkeley; **Carla J. Boyer**, Wilbur Smith Associates; **Eric M. Fujita**, Division of Atmospheric Sciences of the Desert Research Institute; **Katherine F. Turnbull**, Texas A&M University; **Alan J. Krupnick**, Resources for the Future; and **Kathleen C. Weathers**, Institute of Ecosystem Studies.

Disposal of Slightly Radioactive Materials

The Nuclear Regulatory Commission regulates the use of uranium and other nuclear substances and establishes guidelines for managing the thousands of tons of slightly radioactive materials and equipment generated during the normal operation of nuclear facilities and machinery. For three decades, the Nuclear Regulatory Commission has been trying to find safe and cost-effective ways of disposing of slightly radioactive materials. Currently, these materials are either sent to specially designed waste disposal facilities or are recycled and reused, which could expose people to small amounts of radioactivity. Decisions are made by the Nuclear Regulatory Commission and some states on a case-by-case basis.

The Nuclear Regulatory Commission asked the National Research Council (NRC) to suggest changes to the decision-making process and to determine if national standards could be established based on existing technical information. The NRC concluded that the Nuclear Regulatory Commission decision-making process would be improved by allowing more input from stakeholders and the general public. The study proposed a new framework that would include assessments of health, economic, and environmental impacts, among other factors.

The committee also reviewed NUREG-1640, a draft report the Nuclear Regulatory Commission intends to use for technical guidance on future policy revisions. The committee concluded that a state-of-the-art methodology is proposed for assessing the potential health effects associated with salvage or disposal. However, the committee recommended that the regulation also include consideration of more disposal scenarios, the pathways by which people could be exposed, and the impact of human error on predicted exposure levels.

The report outlines how the commission can evaluate the potential impacts of three disposal scenarios: clearance, conditional clearance, and no release. The committee cautioned that its recommendations apply only to slightly radioactive solid materials licensed by the Nuclear Regulatory Commission and participating states and not to the disposition of materials from nuclear weapons.

NAE members on the committee

were **Richard S. Magee** (chair), Carmagen Engineering, Inc.; **Jack Brenizer**, Pennsylvania State University; **Rebecca R. Rubin**, Environmental Projects Manager, Businesses of Adams, Hargett and Riley, Inc.; and **Richard I. Smith**, Pacific Northwest Laboratory.

The full text report, *The Disposition Dilemma: Controlling the Release of Solid Material from Nuclear Regulatory Commissioned Licensed Facilities*, can be viewed at <*www.nap.edu*>.

Preliminary Study for a Nationwide Identity System

In light of the terrorist attacks on September 11, the National Science Foundation, Office of Naval Research, General Services Administration, Federal Chief Information Officers' Council, Social Security Administration, and Vadasz Family Foundation is sponsoring a study to explore the pros and cons of the development of, and authentication technologies for, a nationwide identity system (IDS). In this preliminary report, the NRC study committee considered potential uses of the system; security issues; privacy issues; technology issues; public policy implications; economic costs; and international models. According to Stephen Kent, chief scientist for information security, BBN Technologies, and committee chair, "The technical challenges, the expense, and the strong potential for infringement on the civil liberties of ordinary citizens demand that any proposed identity system undergo strict public scrutiny and a thorough engineering review. Care must be taken to explore issues and ramifications beforehand, because the social and economic costs of fixing or redesigning such systems after deployment would be enormous."

Many questions were raised about how the system would be used and by whom, the type of data that should be collected about individuals, whether participation should be mandatory or voluntary, whether present legal structures would ensure privacy and due-process rights, how the system might be misused, and how the system might fail. The goal of the report was to promote a broad discussion among the public and policy makers about the desirability of creating and implementing a national IDS. Ideally, an effective, centrally managed network would make it difficult for individuals to assume multiple identities and would be able to track and find individuals. To combat terrorism, the system could create a database for security at airports, require that foreigners use ID cards to enter the United States, and maintain centralized databases for visa holders and other noncitizens. The system could also be used to link all state motor vehicle department records and to provide information for quick background checks on potential gun buyers.

NAE members on the committee are **Michael Angelo**, Compaq Computer Corporation; **Drew Dean**, SRI International; **Stephen Holden**, University of Maryland, Baltimore County; **Radia Perlman**, Sun Microsystems Laboratories; and **Priscilla M. Regan**, George Mason University.

The text of the report, *IDS—Not That Easy: Questions About Nationwide Identity Systems*, can be viewed at <*www.nap.edu*>. The final report (expected in fall 2002) will focus on potential authentication technologies for the system.

Publications of Interest

The following reports have been published recently by the National Academy of Engineering or the National Research Council. Unless otherwise noted, all publications are for sale (prepaid) from the National Academy Press (NAP), 2101 Constitution Avenue, N.W., Lockbox 285, Washington, DC 20055. For more information or to place an order, contact NAP online at *http://www.nap.edu* or by phone at (800) 624-6242. *(Note: Prices are subject to change without notice. Online orders receive a 20 percent discount. Please add $4.50 for shipping and handling for the first book and $0.95 for each additional book. Add applicable sales tax or GST if you live in CA, DC, FL, MD, MO, TX, or Canada.)*

Protecting People and Buildings from Terrorism: Technology Transfer for Blast-Effect Mitigation. This National Research Council report recommends that the DOD Defense Threat Reduction Agency (DTRA) step up its efforts to share with the civilian community and other federal agencies the results of a research and testing program for protecting people and buildings from bomb blasts; these results should then be used to inform state and local building codes. It also recommends that technical and professional societies become more involved in the technology-transfer process. The report urges the federal government to set up rapid-response teams to collect medical information about injuries, illnesses, and casualties that result from bombing attacks and to develop a database to store and analyze the information. The design, selection, and arrangement of nonstructural features, such as office equipment, to prevent additional damage or injury should also be addressed. Security measures for mainframe computers and communications equipment should be addressed during the design process rather than after the fact. Paper, $18.00.

Diversity in Engineering: Managing the Workforce of the Future. This volume contains 15 presentations from a workshop, hosted by the National Academy of Engineering (NAE), on best practices in managing diversity in the engineering workforce. Talks by NAE president **Wm. A. Wulf**, IBM vice president **Nicholas Donofrio**, and Ford vice president **James Padilla** focused on the business case for diversity. Representatives of leading employers of engineers discussed ways to improve the recruitment, retention, and advancement of women and underrepresented minorities. Other speakers talked about mentoring, globalization, affirmative action backlash, and dealing with lawsuits. The workshop was attended by corporate engineering and human resources managers, who engaged in discussions of these and other issues facing businesses that employ engineers. Summaries of the discussions are also included. Paper, $33.75.

Engineering and Environmental Challenges: Technical Symposium on Earth Systems Engineering. The Earth is no longer completely controlled by natural processes. Today our planet is influenced, or even controlled, by humans. In response to that change, a new area of study, Earth systems engineering, is emerging based on holistic solutions to complex problems. The essays in this volume focus on climate change, energy from biological systems, megacities of the future, and environmental and technological policy making. Taken as a whole, they highlight the crucial importance of interactions among natural processes, human activities, and technology. First presented at the National Academy of Engineering Symposium on Earth Systems Engineering, these papers point up the opportunities and challenges facing engineers, and indeed all of humanity. Paper, $29.75.

Naval Mine Warfare: Operational and Technical Challenges for Naval Forces. This study, requested by the Chief of Naval Operations, examines issues related to both countermining and future sea mining capabilities. The recommendations include the establishment of mine warfare as a major area of naval warfare; greater emphasis on intelligence, surveillance, and reconnaissance; the reestablishment of a naval mining capability; and the modernization of the dedicated force for mine countermeasures. Paper, $44.75.