EPRI JOURNAL®

SUMMER 2000

About EPRI®

EPRI creates science and technology solutions for the global energy and energy services industry. U.S. electric utilities established the Electric Power Research Institute® in 1973 as a nonprofit research consortium for the benefit of utility members, their customers, and society. Now known simply as EPRI, the company provides a wide range of innovative products and services to more than 1000 energy-related organizations in 40 countries. EPRI's multidisciplinary team of scientists and engineers draws on a worldwide network of technical and business expertise to help solve today's toughest energy and environmental problems.

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COVER: Sustainable global development, which promotes both environmental stewardship and economic growth, will require a broad portfolio of energy technologies, from cleaner fossil fuel combustion to renewables, fuel cells, and other advanced concepts. (Illustration © 2000 by Stéphan Daigle/Renard Represents)

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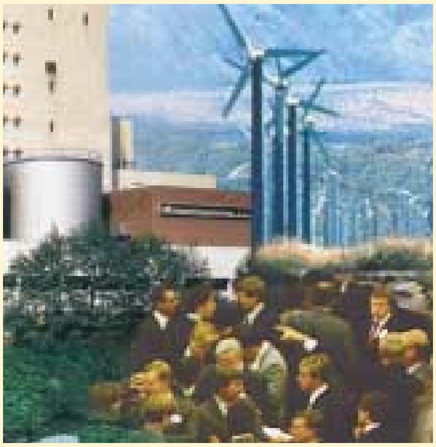

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Power to Liberate the Future

From our vantage point in the United States at the start of the new millennium, the future looks bright. Our nation is at peace, the economy is thriving, crime rates are declining, air and water are cleaner than they have been in many generations, and science and technology are progressing rapidly, with exciting results. It is easy for us to envision a future of continuing peace, progress, and prosperity. Such a vision, however, is not universally shared. While economic development is evident across much of the world, global population continues to rise and to concentrate in overcrowded megacities. Many people live in poverty and lack access to the resources, infrastructure, and education that would enable them to improve the quality of their lives. Pollution, especially in urban growth centers, is becoming worse. Potential environmental problems that could have a global impact—irreversible climate change, biodiversity collapse, and the spread of untreatable diseases, to name a few—are causing increasing concern.

Whether or not these specific problems become reality, they raise profound questions: Can global development and economic expansion be continued? Will development activities do irreversible harm to the environment? Will we deplete critical, irreplaceable resources or otherwise preclude future generations from providing for their own welfare? These are some of the core issues that define the challenge of global sustainability.

While formidable, the challenge is not insurmountable. Past centuries have brought previously unimagined advances in the ability to provide for the needs of people. These advances have occurred in the face of shortages, ignorance, and uncertainty far greater than what we face today. It is indisputable that humanity's unique abilities to conceive, develop, and apply technology and to pass along experience and knowledge have been liberating—moving us from clubs and spears to mechanized agriculture, from steam engines to electricity, from charcoal to the printing press to the telephone to satellite communications. The past teaches that technology can be a liberating force, as long as it is applied with respect for its potential ramifications. The recent record in the United States gives hope that technologically driven development will bring with it mediating forces and favorable trends across the globe. The record also suggests that sustainability may best be achieved by allowing these forces to work the same magic in the developing world that they have in the developed one.

Imagining and striving for a sustainable future are crucial for society. Realizing such a future will certainly require greater economic and political incentives for international cooperation, but the technological tools for promoting sustainable development must also be provided. History has clearly shown that affordable energy is one of those tools. It continues to be a key driver of economic growth, allowing developing countries to build an industrial base and develop economic, social, and health infrastructures to serve the needs of their populations.

The unique attributes of electricity—especially its end-use efficiency, versatility, and cleanliness—make it indispensable for satisfying future energy needs in a sustainable context. Building on these attributes, the EPRI-initiated Electricity Technology Roadmap puts forward a vision of a sustainable future that will allow our children, their children, and generations beyond to cope effectively with the problems they will face here and around the world.

Now as in the past, technology can liberate humanity from perceived limits. Creative people and institutions with energy, intellect, and optimism will foster the availability and acceptance of sustainable technologies—technologies that will enable present and future populations to seek brighter, more fulfilling lives. Let us begin.

Michael Miller

Michael Miller
Director, Environment

Contributors

Technology and the Quest for Sustainability (page 8) was written by Brent Barker, former editor of the *EPRI Journal*.

Brent Barker is manager of corporate communications, having earlier served as manager of strategic and executive communications and for 12 years as the *Journal*'s editor-in-chief. For the past two years, he has been actively engaged in the development and synthesis of the Electricity Technology Roadmap. Before joining EPRI in 1977, Barker worked as an industrial economist and staff author at SRI International and as a commercial research analyst at USX Corporation. He graduated in engineering science from Johns Hopkins University and earned an MBA at the University of Pittsburgh.

The Value of Greenhouse Gas Emissions Trading (page 18) was written by Taylor Moore, *Journal* senior feature writer, with assistance from Tom Wilson of EPRI's Science and Technology Development Division.

Tom Wilson is a technical manager in the global climate change research program. His current work focuses primarily on the role of technology in addressing climate concerns, on emissions trading and other options for reducing the costs of achieving environmental goals, and on strategic environmental planning for individual utilities. Earlier he managed EPRI's efforts to assess the potential economic and noneconomic effects of climate change. Before joining EPRI in 1985, Wilson worked at ICF Incorporated, Stanford's Energy Modeling Forum and International Energy Program, and Brookhaven National Laboratory. He holds a BS degree in statistics from the University of North Carolina at Chapel Hill and MS and PhD degrees in operations research from Stanford University.

E-EPIC: Analyzing Emissions Policies (page 26) was written by Gordon Hester of EPRI's Science and Technology Development Division.

Gordon Hester, manager of energy analysis, specializes in decision strategies for cost-effective environmental management—including emissions trading for the control of sulfur dioxide, nitrogen oxides, and greenhouse gases; effluents trading for the attainment of water quality goals; economic analysis of air quality control policies; and electric and magnetic field risk management. Before coming to EPRI in 1990, he was a researcher at Carnegie Mellon University, where his work focused on risk communication, particularly with respect to EMF and radon. Earlier Hester spent four years as a public policy analyst for the Minnesota state government. He received a BS degree in economics from Southern Oregon State College and a PhD in public policy analysis from Carnegie Mellon.

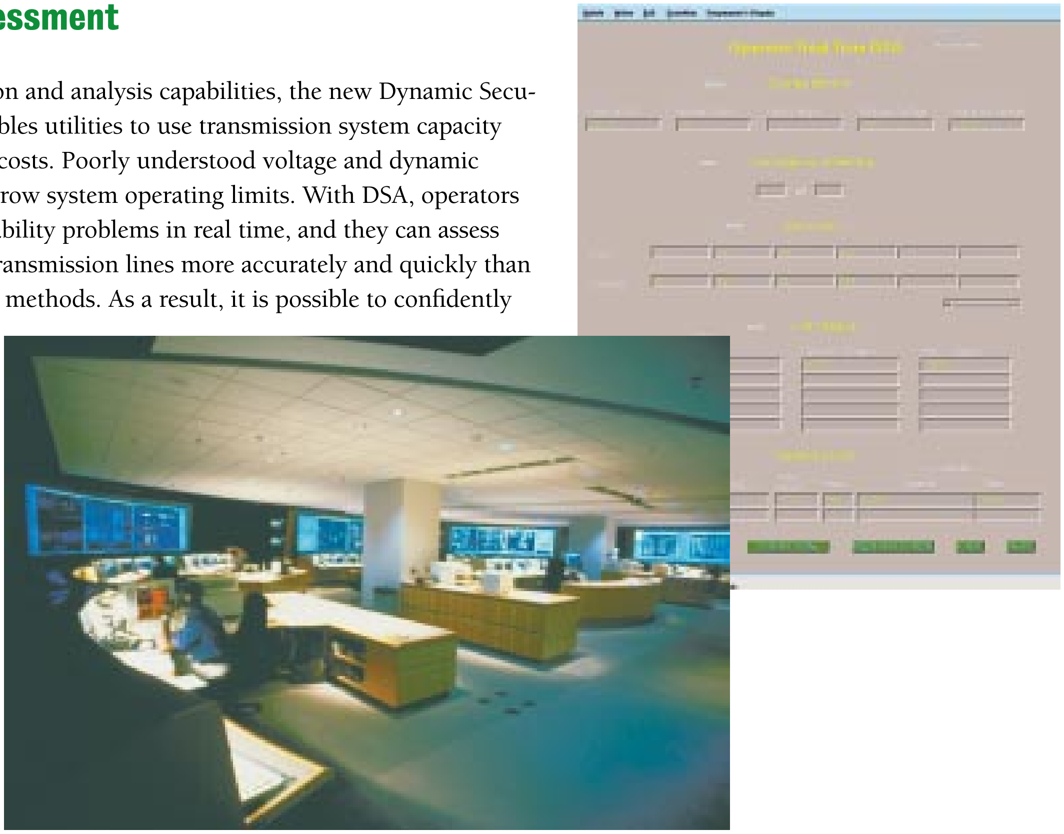
Products

Deliverables now available to EPRI members and customers

Dynamic Security Assessment

By providing on-line calculation and analysis capabilities, the new Dynamic Security Assessment software enables utilities to use transmission system capacity more efficiently and thus reduce costs. Poorly understood voltage and dynamic constraints can unnecessarily narrow system operating limits. With DSA, operators can detect and analyze system stability problems in real time, and they can assess actual transfer limits on critical transmission lines more accurately and quickly than they can with traditional analysis methods. As a result, it is possible to confidently operate closer to system limits. EPRI and Northern States Power recently sponsored a demonstration of the DSA software at NSP's Minneapolis control center.

■ *For more information, contact Peter Hirsch, phirsch@epri.com, 650-855-2206. To order DSA, contact Jim Waight at Siemens Power Systems Control, 612-536-4142.*


RICK SOUTHER, COURTESY NORTHERN STATES POWER CO.

UCA 2.0 Published by IEEE

The version 2.0 specification of EPRI's Utility Communications Architecture (UCA™), which uses open-system protocols to enable device interoperability and database interconnectivity, has been published by the IEEE Standards Association in a two-volume report (IEEE-SA TR 1550). UCA is also being reviewed by the International Electrotechnical Commission, which is expected to designate it the international standard for integrated utility communications by the end of this year. Over two dozen North American power companies and five international utilities are testing and implementing UCA technology, and more than 20 vendors provide UCA-conforming hardware and software. UCA compatibility can be added to nearly any electronic device by means of a card smaller than a credit card.

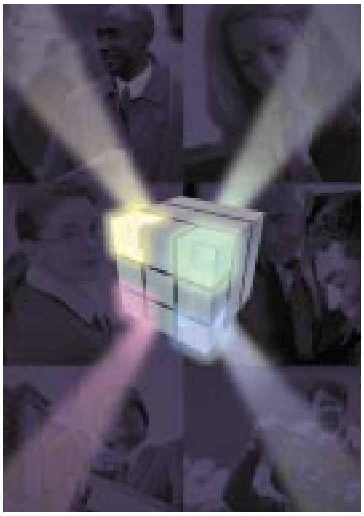
■ *For more information, contact Bill Blair, bblair@epri.com, 650-855-2173. The IEEE-SA report can be ordered on-line at www.standards.ieee.org/catalog/press/index.html#uca or through a link at www.epri.com.*

NDE Personnel Qualification Testing Software

Since nondestructive evaluation is vital in assessing the integrity of critical nuclear components, the performance of NDE personnel is an issue that utilities with nuclear plants constantly address. To facilitate personnel testing, EPRI developed—and has recently upgraded—software for creating unique, randomized written examinations that can be taken on a computer. Called the NDE Personnel Qualification Testing Software, this product complements a basic eddy-current training course that emphasizes heat exchanger evaluation. The new upgrade, version 2.0, is Y2K compliant and operates on Microsoft Windows 95, 98, and NT platforms.

■ *For more information, contact Nathan Muthu, nmuthu@epri.com, 704-547-6046. To order the software (AP-112535-CD), call EPRI Customer Service, 800-313-3774.*

COURTESY ENTERGY OPERATIONS



Custom-ER Software

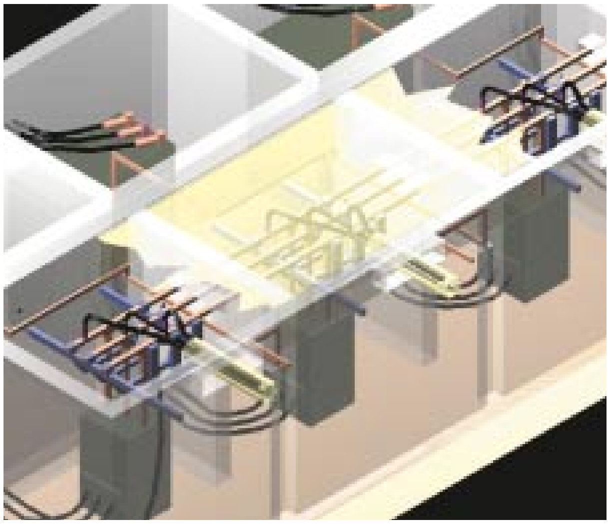
The customer information systems traditionally used by utilities—commodity-oriented systems tied to back-office revenue management operations—are ill suited to today's competitive objectives of gaining and retaining market share. EPRIsolutions has collaborated with Appreciated Software of Orinda, California, in introducing Custom-ER™, a suite of software modules that apply a new, front-office business model in a complete rethinking of the way utilities manage their customer relationships. One new module, described in EPRI report TR-114254-R1, is a fast, flexible, easy-to-use retail billing engine that can handle complex pricing and packaging options to give customers the billing arrangements they prefer. Like the other Custom-ER modules, the billing engine can be installed individually.

■ *For more information, contact David Cain, dcain@epri.com, 650-855-2112. To order Custom-ER, call Appreciated Software, 925-254-6743. To order TR-114254-R1, call EPRI Customer Service, 800-313-3774.*

MagShield 1.0

MagShield 1.0 is a state-of-the-art analytical tool for designing and evaluating the ferromagnetic and conductive shielding used to reduce 60-Hz magnetic fields in offices, laboratories, and other building spaces. Unlike earlier software, MagShield has three-dimensional capabilities for modeling the shielding of complex electrical systems. Although concerns that exposure to 60-Hz magnetic fields may have adverse health effects have diminished, the fields have increasingly been associated with interference problems in computers and other electronic equipment. Verified in field tests, MagShield is expected to be useful for designing shields that eliminate such problems. It runs on Microsoft Windows 95, 98, and NT 4.0 operating systems and requires a Pentium 90 or faster processor.

■ *For more information, contact Frank Young, fyoung@epri.com, 650-855-2815. To order the software (AP-114730), call EPRI Customer Service, 800-313-3774.*

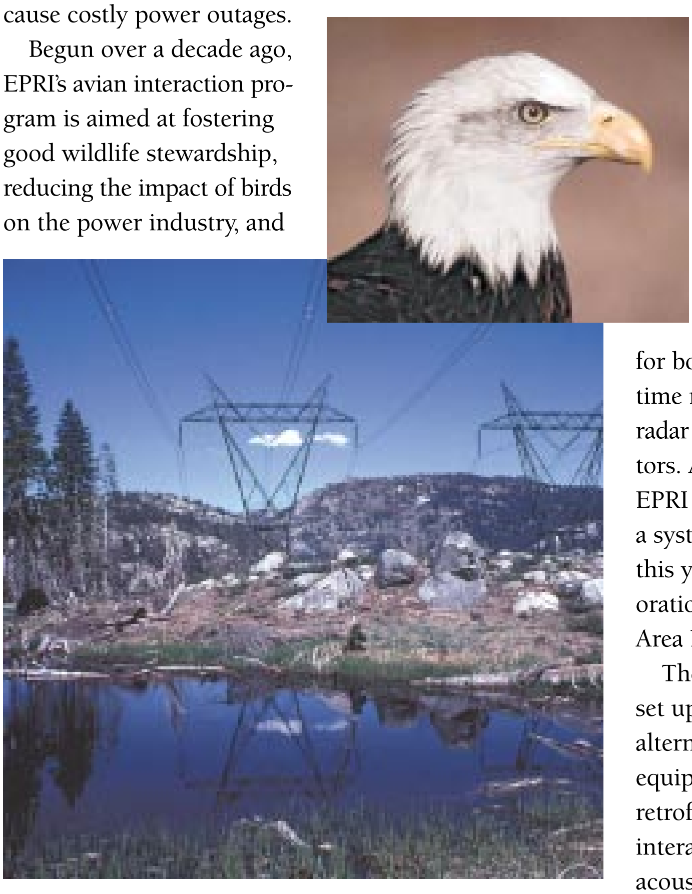


Project Startups

New ventures of importance to power and service providers

Monitoring Bird Activity Around Utility Equipment

Electricity demand growth and the spread of power delivery infrastructure continue to prompt concerns about the safety of birds around utility equipment. Collisions and electrocutions not only harm avian populations but also can cause costly power outages.



Begun over a decade ago, EPRI's avian interaction program is aimed at fostering good wildlife stewardship, reducing the impact of birds on the power industry, and helping utilities comply with legal requirements enforced by the U.S. Fish and Wildlife Service. These regulations include provisions of the Endangered Species Act, the Bald and Golden Eagle Protection Acts, and the Migratory Bird Treaty Act.

Last year, EPRI brought together utility engineers, biologists, and wildlife personnel from around the world at a conference on birds and utility equipment. Attendees at the Charleston, South Carolina, conference discussed current problems and ideas for solving them. "There's no shortage of great ideas," says Rick Carlton, manager for quantitative ecology in EPRI's Science and Technology Development Division, "but many of the methods have not been thoroughly tested."

To study some of the most promising methods for reducing collisions and electrocutions, EPRI is working with the Fish and Wildlife Service, the California Energy Commission, utilities, and other groups to develop a system for monitoring bird activity. The system will consist of video cameras for both daytime and nighttime recording, as well as radar and acoustic monitors. According to Carlton, EPRI anticipates that such a system will be deployed this year in tailored collaboration with the Western Area Power Administration.

The video cameras can be set up at problem sites or, alternatively, at sites where equipment has already been retrofitted to reduce avian interactions. The radar and acoustic monitors will detect the approach of birds and determine their number, species, size, and flight patterns. As the birds get nearer, the monitors will cue the video cameras to begin recording. The resulting information will be helpful to utilities in identifying the exact nature of problems and also in testing mitigation methods before retrofitting miles of power lines.

As well as monitoring bird activity, researchers will have to consider wind and weather conditions, which can affect birds' flight patterns and their actual interactions with power equipment. Wet weather, for example, can make a bird's feathers more conductive, increasing the potential for electrocution.

Workshop attendees learned that, in addition to power structures, communication towers can pose a particular hazard to birds. Birds that migrate at night, such as thrushes, warblers, and vireos, are liable to collide with lighted towers exceeding 200 feet (60 meters). They are especially at risk during foggy, misty, or low-cloud-cover conditions, when flashing tower lights actually attract birds. There are more than 68,000 of these towers in the United States. Partnerships with the communications industry (including the radio, television, cellular, and microwave sectors) have been proposed to address this problem.

■ *For more information, contact Rick Carlton, rcarlton@epri.com, 650-855-2115.*

Brain Power Applied to Power Grid Operation

The increasing complexity and interconnectedness of the national energy, telecommunications, transportation, and financial infrastructures pose new challenges for secure, reliable management and operation. Some of the country's best minds in the fields of applied mathematics, power systems, and computer science are addressing these challenges in a five-year, $30 million initiative sponsored by EPRI and the Department of Defense. This effort, called the Complex Interactive Networks/Systems Initiative (CIN/SI), is part of the Government-Industry Collaborative University Research program.

CIN/SI is funding work on network modeling, measurement, control, and operations and management. Products will include techniques for understanding the true behavior of dispersed, heterogeneous interconnected systems; tools to mitigate

and prevent cascading effects through and between networks; and technologies for robust distributed control and self-regulation.

One innovation being explored is the use of computer-based “intelligent agents” for distributed sensing, computation, and control. Intelligent agents have the potential to provide for an adaptive response to a disturbance at the site where it occurs. An intelligent power grid, for example, would be capable of automatic reconfiguration in the event of material failures and other destabilizing disturbances.

“The objective of CIN/SI is to develop techniques that will enable complex, interconnected national infrastructures to be self-stabilizing, self-optimizing, and self-healing,” says Massoud Amin, EPRI manager for mathematics and information science. These capabilities would result in unprecedented network reliability, robustness, efficiency, and—in the case of electricity—power quality.

CIN/SI Projects and Lead Universities

- A mathematical foundation for complex interactive networks (California Institute of Technology)
- Context-dependent network agents (Carnegie Mellon University)
- Analytical, communications, and control tools for minimizing network failures while maintaining efficiency (Cornell University)
- Rapid-simulation tools for improving network robustness and accelerating fault detection (Harvard University)
- Anticipatory, multiagent computing for intelligent management of the power grid (Purdue University)
- Wide-area monitoring and self-healing techniques for protection against catastrophic power grid failures (University of Washington)

Six consortia comprising 28 universities and 2 energy companies are performing the research; the areas of investigation and lead universities are listed in the previous column. For an executive summary of CIN/SI, go to EPRI’s public Web site (www.epri.com), select Transmission Systems, then the Grid Operations and Management area, and then Strategic S&T Initiatives.

■ *For more information, contact Massoud Amin, mamin@epri.com, 650-855-2452.*

Program Addresses Infrastructure Security

Recent hacking incidents that halted e-business on several high-profile Web sites have fueled concerns about the potential for disruptions of the critical interdependent systems supporting the global energy infrastructure. To address these concerns, EPRI has initiated a program on security issues that affect the energy industry.

“The immediate focus is to determine the vulnerabilities of all the industry’s electronic systems—not only business systems but also systems that monitor and control operational processes and provide critical communications capabilities,” says EPRI’s Charlie Siebenthal, manager of the new Enterprise Infrastructure Security (EIS) program. “In the long run, the emphasis will shift to the development and implementation of electronic security policies and programs to augment companies’ physical security programs.”

Modeled on EPRI’s successful Y2K information-sharing initiative, the EIS program will serve as a focal point for the energy industry’s technical response to concerns about infrastructure security. The program is sponsoring a series of workshops covering broad security issues, specific technical topics, and security-related legal issues. (The first workshop was held this past April.) A controlled-access Web site has been developed to serve both as a communications forum for program participants and as a place where they can promptly obtain the security information collected and generated in the program. Various reference documents will also be produced.

Program participation is open to any company actively engaged in the production, transportation, distribution, or sale of energy. Says Siebenthal, who also serves as cochair of the information-sharing working group of the National Partnership for Critical Infrastructure Assurance, “I believe EPRI’s EIS program will provide an opportunity for the energy industry to move to the forefront of the effort to ensure information security throughout the entire business community.”

■ *For more program information, contact Susan Marsland, smarslan@epri.com, 650-855-2946, or go to eis.epri.com. For technical information, contact Joe Weiss, joeweiss@epri.com, 650-855-2751.*

ANTHONY LUKBAN

Technology and the

Quest for Sustainability

Emerging from the hardships of the last ice age (circa 10,000 BC), an invigorated human species unleashed its ingenuity for toolmaking and social order on a temperate and inviting world. The tools of early agriculture led in succession to food surpluses, the formation of protocities, increased work specialization, more rapid learning, and the development of increasingly sophisticated technology and engineering. The global population slowly grew over the course of 11,000 years from around 5 million hunter-gatherers to 50 million farmers, villagers, warriors, and nobles. By 1000 AD, the wholesale clearing of the forests of Europe had begun in earnest, making way for a new, still larger wave of population growth. By the 1600s, vast tracts of forests had been converted to farms and pastures, with wood sufficiently scarce that energy prices in Europe soared and city folk turned to alternatives, notably the more compact and efficient coal. By the 1700s, the forests of the New World beckoned as the one unbounded source of farmland and of the prodigious amounts of wood and energy required for glassmaking, shipbuilding, and other early industries.

The world is threatened by a basic conflict between the need to preserve finite, sometimes delicate environmental resources and the desire of a growing population to promote economic development and a better quality of life. Despite this centuries-old problem, there are encouraging signs that barriers to a sustainable future will yield to technology and a growing understanding of the problems and opportunities of the coming century.

By 1800, with the world population pushing 1 billion people, the seemingly infinite earth was proving to have boundaries after all. Thomas Malthus put

by Brent Barker

the equation together. Global population would inevitably outstrip the food supply, he asserted in his famous essay of 1798, because population would increase geometrically while the conversion to cropland could increase only linearly. The logic was flawless, based on his observation that the 9 million people in England were already straining that country's food supply, but the message was not well received. Malthus was pitting sober reality against the utopian temper of the time. His field of economics became known as the dismal science, and in our time his name is synonymous with pessimism and wrongheadedness. He died firm in his beliefs, just before the industrial age and its impact on agriculture undercut his premise and just before a young Charles Darwin saw in Malthus's essay the light of a new theory about what happens to a species struggling for survival in the face of an oversubscribed food source—evolution or extinction. Darwin went on to fame, Malthus to notoriety.

Malthus was in fact right in his extrapolation about population, but he failed to envision what at the time seemed to be impossible—that a surge in agricultural productivity due to technical innovation would catch up to and eventually overtake the geometric growth in population. In the past 200 years, global population has increased 600% while agricultural output has increased 700%. Farm productivity has greatly extended the carrying capacity of the earth and offers us a strong hint about how to approach global sustainability in the coming century.

Sustainability has been the subject of much discussion and a steady stream of policy forums since the World Commission on Environment and Development, headed by Dr. Gro Brundtland, put it on the world stage in 1987. The Brundtland Commission defined sustainable development as growth that meets the needs of the present generation without compromising the ability of future generations to meet their needs. As such, sustainability carries with it the distinct feeling of a modern problem. But it is not. We have been on a seemingly unsustainable course for hundreds of years, but the rules, stakes, and speed of the game keep changing, in large part because of our ability to use technology to extend limits and to magnify human capabilities. As long as the population continues to consume a finite store of resources, we must continue to change our course or fail. If, with the global population approaching 9–10 billion people by midcentury, we were to lock in current technologies and development patterns, we would likely find ourselves heading toward environmental disaster or worse. Our best hope—perhaps our only hope—is to evolve rapidly enough, using our ingenuity, our technology, and our growing ethical framework of inclusiveness and respect for the diversity of life, to stay ahead of the proverbial wolf. Despite the environmental pessimism of the current age, there are a handful of signs that suggest we are struggling in fits and starts in the right direction, possibly even gaining more ground than we are losing.

ART ON PAGE 8 BY BOB MATTHEWS/MATTHEWS DESIGN GROUP

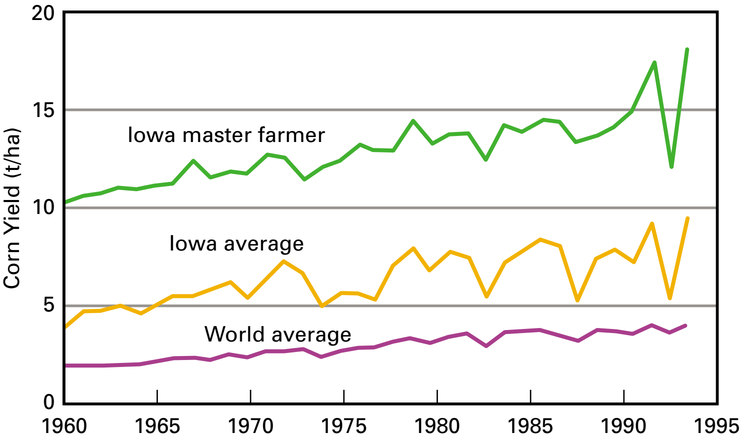
Farm productivity is one of the most significant of the great reversals in human fortune that have occurred in recent times, reversals that offer both hope and strategic guidance. Largely as a result of crop yields growing at 1–2% per year, the millennia-old pattern of clearing forests and grassland for farms and pastures has begun to be reversed in some regions of the world. According to one of the world's leading scholars on technological change, Arnulf Grübler of the International Institute for Applied Systems Analysis, some 18 million hectares (45 million acres) of cropland in Europe and North America have been *reconverted* to forest and grassland between 1950 and 2000, while agricultural output in those regions has continued to grow.

Great reversals are also beginning to occur in areas as diverse as population, resource utilization, energy, and transportation. Fertility rates continue to drop below the replacement level (2.1 children per woman) in affluent nations. First evident in France more than a century ago, the preference for smaller families is spreading throughout the world as economic development expands. As a result, roughly 90% of the population growth in the next 50 years will occur in today's poorest nations. Overall, we are looking at a new demographic dynamic in which population is exploding in some parts of the world while imploding in others. Nevertheless, it is significant that year after year the United Nations continues to crank down its projection of global population in the twenty-first century, suggesting greater certainty that the population is leveling off.

Although the consumption of resources continues to grow with population and economic prosperity in all parts of the world, there are some intriguing countertrends. Technology continues to expand the menu of material resources—for example, alloys, composites, and ceramics—as well as to increase the efficiency with which we use them. Both trends help keep resource depletion at bay. Moreover, usage patterns are now rapidly shifting, at least in the developed nations, toward lighter materials (aluminum, plastics, paper) and toward the recycling of heavier materials (steel, copper, zinc) and of manufactured components. Perhaps most important for the future, however, is the trend toward the "immaterial." The information age is rapidly knitting together a new economy based on immaterial, knowledge-based assets, electronic commerce, and virtual transportation—an economy that is growing much faster than the old economy. We can barely glimpse the networked world of the future, but we can assume it will be much less dependent on natural resources.

The reversal in energy use is more clearcut. Energy is in the middle of a 300-year trend away from fossil fuels. After more than 100,000 years of wood use, the global energy system began in the nineteenth century to move toward progressively cleaner, less carbon-intensive fuels (shifting from wood to coal to oil to gas). In fact, the decarbonization of the global energy system has been systematically proceeding at an average rate of 0.3% per year for the last 150 years, while the economic productivity of energy use has been improving at a rate of about 1% per year. The combined result (1.3% per year) is a healthy rate of reduction in the carbon used (and emitted) in producing a dollar of goods and services around the world. Even though the energy productivity improvements have thus far been eclipsed by the growth in en-

Simply sharing modern technology and best practices with the developing world can spur tremendous gains in global productivity. In agriculture, for example, U.S. crop yields are about twice the world average, and the best Iowa farmer can again double the yield through the use of advanced equipment and know-how. If the average global yield could be brought up to today's U.S. average over the next 50 to 70 years, the world could feed 10 billion people a diet of 3000 calories a day while sparing half of today's farmland.



KATHY MARTY

ergy consumption (as more people engage in more economic activity), the trend is telling. The eventual result may be the same as in agriculture, with productivity improvements overtaking aggregate demand. In terms of decarbonizing the energy system, the transition is likely to be complete sometime in the next 75–150 years, depending on how fast we push the innovation process toward a clean, electricity- and hydrogen-based system. We would eventually get there even without a rigorous push, but as we will see later, the urgency of the climate change issue may force us to speed up the historical trend by a factor of 2 or 3.

The power of technology

These historical trends in agriculture, land use, resource consumption, and energy use point to some profound opportunities for the future. There are at least four major ways in which technology has great potential for helping us achieve a sustainable balance in the twenty-first century.

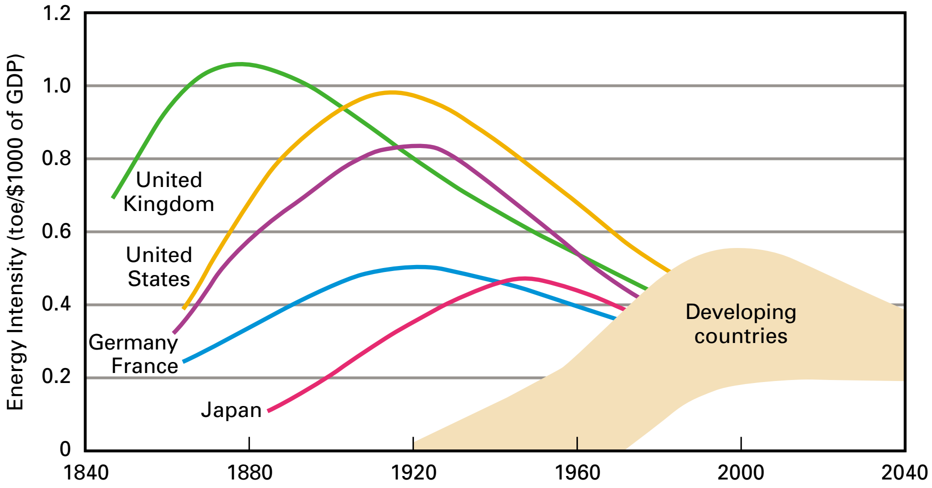
The first area of opportunity for technology is in the acceleration of productivity growth. In agriculture, for example, corn yields in the world today average only about 4 tons per hectare, while the United States averages 7 tons per hectare and the best Iowa farmer can get 17 tons. Simply bringing the world as a whole up to today's best practices in the United States would boost farm productivity to unprecedented heights, even without considering what the biological and genetic revolutions may hold in store for agriculture in the next century.

As for the overall productivity growth rate in industry and business, we are finally starting to register an increase after nearly 30 years of subpar performance at around 1% growth per year. Computerization appears to be taking hold in the economy in new and fundamental ways, not just in speeding up traditional practices but in altering the economic structure itself. One historical analogy would be the introduction of electric unit drives just after World War I, setting in motion a complete reorganization of the manufacturing floor and leading to a surge in industrial productivity during the 1920s.

In the twenty-first century, industrial processes will be revolutionized by new electrotechnologies, including lasers, plasmas, microwaves, and electron beams for materials processing, as well as electrochemical synthesis and electroseparation for chemical processing. Manufacturing will be revolutionized by a host of emerging technology platforms—for example, nanotechnology, biotechnology, biomimetics, high-temperature superconductivity, and network technology, including the combining of advanced sensors with information technology to create adaptive, intelligent systems and processes. Future industrial facilities using advanced network technologies will be operated in new ways to simultaneously optimize productivity, energy use, materials consumption, and plant emissions. Optimization will extend beyond the immediate facility to webs of facilities supporting industrial and urban ecology, with the waste of one stream becoming the feedstock of the next. In the aggregate, the penetration of all the emerging technologies into the global economy should make it possible to sustain industrial productivity growth rates above 2% per year for many decades.

The same technology platforms will be used to improve the efficiency of land, energy, and water use. For example, distributed sensors and controls that enable precision farming can improve crop yields and reduce land and water use. And doubling or even tripling global energy efficiency in the next century is well within our means. Given the inefficiencies that now exist at every stage in the process—from mining and drilling for fuel through the use of energy in automobiles, appliances, and processes—the overall efficiency of the energy chain is only about 5%.

From a social standpoint, accelerating productivity is not an option but rather an imperative for the future. It is necessary in order to provide the wealth for environmental sustainability, to support an aging population in the industrialized world, and to provide an economic ladder for developing nations.



Nations have traditionally followed similar development paths as they grew economically, with energy intensity—shown here as the amount of energy (in tons of oil equivalent) needed to produce $1000 of goods or services—first rising and then falling as advanced technology and widespread electrification increased efficiency. Using modern industrial and commercial electrotechnologies would allow today's developing countries to leapfrog the less-efficient processes of the past, conserve resources, and build their economies more quickly. (Source: A. Reddy and J. Goldemberg, "Energy for the Developing World," *Scientific American,* September 1990, p. 112.)

The second area of opportunity for technology lies in its potential to help stabilize global population at 10–12 billion sometime in the twenty-first century, possibly as early as 2075. The key is economics. Global communications, from television to movies to the Internet, have brought an image of the comfortable life of the developed world into the homes of the poorest people, firing their own aspirations for a better quality of life, either through economic development in their own country or through emigration to other countries. If we in the developed world can make the basic tools of prosperity—infrastructure, health care, education, and law—more accessible and affordable, recent history suggests that the cultural drivers for producing large families will be tempered, relatively quickly and without coercion.

But the task is enormous. The physical prerequisites for prosperity in the global economy are electricity and communications. Today, there are more than 2 billion people living without electricity, or commercial energy in any form, in the very countries where some 5 billion people will be added in the next 50 years. If for no other reason than our enlightened self-interest, we should strive for universal access to electricity, communications, and educational opportunity. We have little choice, because the fate of the developed world is inextricably bound up in the economic and demographic fate of the developing world.

A third, related opportunity for technology is in decoupling population growth from land use and, more broadly, decoupling economic growth from natural resource consumption through recycling, end-use efficiency, and industrial ecology. Decoupling population from land use is well under way. According to Grübler, from 1700 to 1850 nearly 2 hectares of land (5 acres) were needed to support every child born in North America, while in the more crowded and cultivated regions of Europe and Asia only 0.5 hectare (1.2 acres) and 0.2 hectare (0.5 acre) were needed, respectively. During the past century, the amount of land needed per additional child has been dropping in all areas of the world, with Europe and North America experiencing the fastest decreases. Both crossed the "zero threshold" in the past few decades, meaning that no additional land is needed to support additional children and that land requirements will continue to decrease in the future.

One can postulate that the pattern of returning land to nature will continue to spread throughout the world, eventually stemming and then reversing the current onslaught on the great rain forests. Time is critical if vast tracts are to be saved from being laid bare, and success will largely depend on how rapidly economic opportunities expand for those now trapped in subsistence and frontier farming. In concept, the potential for returning land to nature is enormous. Futurist and scholar Jesse Ausubel of the Rockefeller University calculates that if farmers could lift average grain yields around the world just to the level of today's average U.S. corn grower, one-half of current global cropland—an area the size of the Amazon basin—could be spared.

If agriculture is a leading indicator, then the continuous drive to produce more from less will prevail in other parts of the economy. Certainly with shrinking agricultural land requirements, water distribution and use around the world can be greatly altered, since nearly two-thirds of water now goes for irrigation. Overall, the technologies of the future will, in the words of Ausubel, be "cleaner, leaner, lighter, and drier"—that is, more efficient and less wasteful of materials and water. They will be much more tightly integrated through microprocessor-based control and will therefore use human and natural resources much more efficiently and productively.

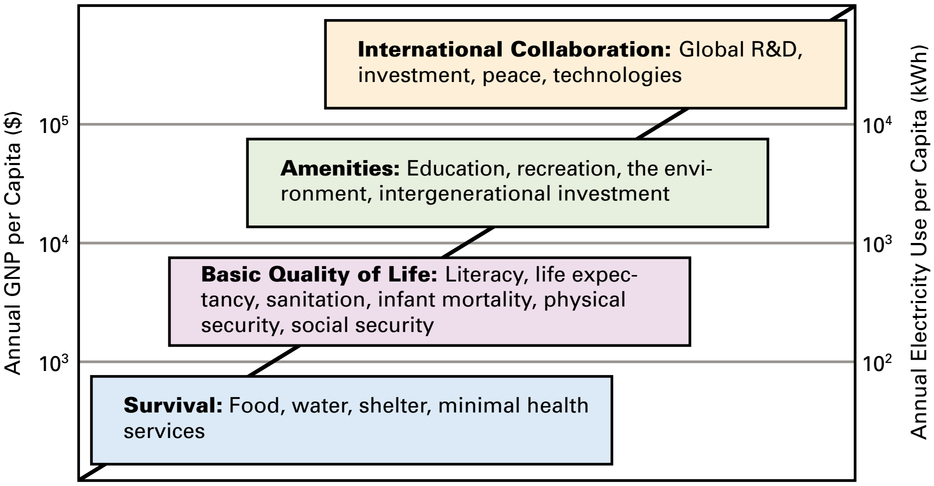
Energy intensity, land intensity, and water intensity (and, to a lesser extent, materials intensity) for both manufacturing and agriculture are already heading downward. Only in agriculture are they falling fast enough to offset the surge in population, but, optimistically, advances in science and technology should accelerate the downward trends in other sectors, helping to decouple economic development from environmental impact in the coming century. One positive sign is the fact that recycling rates in North America are now approaching 65% for steel, lead, and copper and 30% for aluminum and paper. A second sign is that economic output is shifting away from resource-intensive products toward knowledge-based, immaterial goods and services. As a result, although the U.S. gross domestic product (GDP) increased 200-fold (in real dollars) in the twentieth century, the physical weight of our annual output remains the same as it was in 1900. If anything, this trend will be accelerating. As Kevin Kelly, the editor of *Wired* magazine, noted, “The creations most in demand from the United States [as exports] have lost 50% of their physical weight per dollar of value in only six years. . . . Within a generation, two at most, the number of people working in honest-to-goodness manufacturing jobs will be no more than the number of farmers on the land—less than a few percent. Far more than we realize, the network economy is pulling us all in.”

Even pollution shows clear signs of being decoupled from population and economic growth. Economist Paul Portney notes that, with the exception of greenhouse gases, “in the OECD [Organization for Economic Cooperation and Development] countries, the favorable experience [with pollution control] has been a triumph of technology. That is, the ratio of pollution per unit of GDP has fallen fast enough in the developed world to offset the increase in both GDP per capita and the growing number of ‘capitas’ themselves.”

The fourth opportunity for science and technology stems from their enormous potential to unlock resources not now available, to reduce human limitations, to create new options for policymakers and businesspeople alike, and to give us new levels of insight into future challenges. Technically, resources have little value if we cannot unlock them for practical use. With technology, we are able to bring dormant resources to life. For example, it was only with the development of an electrolytic process late in the nineteenth century that aluminum—the most abundant metal on earth—became commercially available and useful. Chemistry unlocked hydrocarbons. And engineering allowed us to extract and put to diverse use untapped petroleum and gas fields. Over the course of history, technology has made the inaccessible accessible, and resource depletion has been more of a catalyst for change than a longstanding problem.

Technology provides us with last-ditch methods (what economists would call substitutions) that allow us to circumvent or leapfrog over crises of our own making. Agricultural technology solved the food crisis of the first half of the nineteenth century. The English “steam crisis” of the 1860s, triggered by the rapid rise of coal-burning steam engines and locomotives, was averted by mechanized mining and the discovery and use of petroleum. The U.S. “timber crisis” that Teddy Roosevelt publicly worried about was circumvented by the use of chemicals that enabled a billion or so railroad ties to last for decades instead of years. The great “manure crisis” of the same era was solved by the automobile, which in a few decades replaced some 25 million horses and freed up 40 million hectares (100 million acres) of farmland, not to mention improving the sanitation and smell of inner cities. Oil discoveries in Texas and then in the Middle East pushed the pending oil crisis of the 1920s into the future. And the energy crisis of the 1970s stimulated the development of new sensing and drilling technology, sparked the advance of non–fossil fuel alternatives, and deepened the penetration of electricity, with its fuel flexibility, into the global economy. Thanks to underground imaging technology, today’s known gas resources are an order of magnitude greater than the resources known 20 years ago, and new reserves continue to be discovered.

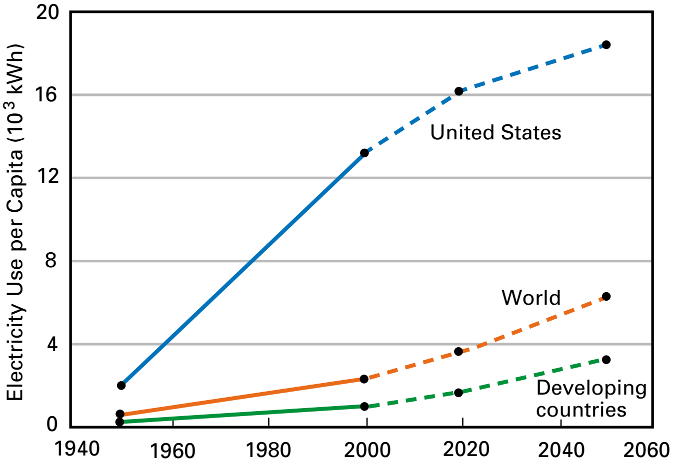
Technology has also greatly extended human limits. It has given each of us a productive capability greater than that of 150 workers in 1800, for example, and has conveniently put the power of hundreds of horses in our garages. In recent decades, it has extended our voice and our reach, allowing us to easily send our words, ideas, images, and money around the world at the speed of light.



EPRI founder Chauncey Starr created this diagram to describe the strong historical correlation between economic prosperity, access to electricity, and social choices. A large majority of the world’s population is now trapped at the lowest economic level, where daily life focuses on meeting the most basic human needs. Only after electricity consumption reaches a threshold of about 1000 kWh per person per year can people afford to devote some of their resources to such amenities as education, the environment, and intergenerational investment.

But global sustainability is not inevitable. In spite of the tremendous promise that technology holds for a sustainable future, there is the potential for all of this to backfire before the job can be done. There are disturbing indications that people sometimes turn in fear and anger on technologies, industries, and institutions that openly foster an ever-faster pace of change. The current opposition to nuclear power, genetically altered food, the globalization of the economy, and the spread of

American culture should give us pause. Technology has always presented a two-edged sword, serving as both cause and effect, solving one problem while creating another that was unintended and often unforeseen. We solved the manure crisis, but automotive smog, congestion, and urban sprawl took its place. We cleaned and transformed the cities with all-electric buildings rising thousands of feet into the sky. But while urban pollution was thereby dramatically reduced, a portion of the pollution was shifted to someone else's sky.



For the developing countries as a group, the Electricity Technology Roadmap targets an annual per capita electricity consumption of at least 3000 kWh by the year 2050, which is slightly higher than the U.S. per capita level of 1950. For the poorest of the world's citizens, the target is at least 1000 kWh per person per year by 2050.

Breaking limits

"Limits to growth" was a popular theme in the 1970s, and a best-selling book of that name predicted dire consequences for the human race by the end of the century. In fact, we have done much better than those predictions, largely because of a factor the book missed—the potential of new technology to break limits. Repeatedly, human societies have approached seemingly insurmountable barriers only to find the means and tools to break through. This ability has now become a source of optimism, an article of faith, in many parts of the world.

Today's perceived limits, however, look and feel different. They are global in nature, multicultural, and larger in scale and complexity than ever before. Nearly 2 billion people in the world are without adequate sanitation, and nearly as many are without access to clean drinking water. AIDS is spreading rapidly in the regions of the world least able to fight it. Atmospheric concentrations of greenhouse gases are more than 30% greater than preindustrial levels and are climbing steadily. Petroleum reserves, expected to be tapped by over a billion automobiles worldwide by 2015, may last only another 50–100 years. And without careful preservation efforts, the biodiversity of the planet could become as threatened in this coming century as it was at the end of the last ice age, when more than 70% of the species of large mammals and other vertebrates in North America disappeared (along with 29% in Europe and 86% in Australia). All these perceived limits require innovation of a scope and intensity surpassing humankind's current commitment.

The list of real-world problems that could thwart global sustainability is long and sobering. It includes war, disease, famine, political and religious turmoil, despotism, entrenched poverty, illiteracy, resource depletion, and environmental degradation. Technology can help resolve some of these issues—poverty and disease, resource depletion, and environmental impact, for example—but it offers little recourse for the passions and politics that divide the world. The likelihood is that we will not catch up and overtake the moving target of global sustainability in the coming century, but given the prospects for technology, which have never been brighter, we may come surprisingly close. We should put our technology to work, striving to lift more than 5 billion people out of poverty while preventing irreversible damage to the biosphere and irreversible loss of the earth's natural resources.

We cannot see the future of technology any more clearly than our forebears did—and for much the same reason. We are approaching the threshold of profound change, moving at great speed across a wide spectrum of technology, ranging today from the Internet to the Human Genome project. Technology in the twenty-first century will be turning toward biological and ecological analogs, toward microminiature machines, toward the construction of materials atom by atom, and toward the dispersion of microprocessor intelligence into everyday objects subsequently linked into neural networks. Computing power continues to double every 18 months, as postulated in Moore's law, promising to enable us to create much more powerful tools for everyday tasks, optimize business services and processes along new lines, understand complex natural phenomena like the weather and climate, and design technical systems that are self-diagnostic, self-healing, and self-learning. The networked, digital society of the future should be capable of exponential progress more in tune with biological models of growth than with the incremental progress of industrial societies.

If history tells us anything, it is that in the long term we are much more likely to underestimate technology than to overestimate it. We are not unlike the excited crowds that in 1909 tried to imagine the future of flight as they watched Wilbur Wright loop his biplane twice around the Statue of Liberty and head back to Manhattan at the record-breaking speed of 30 miles per hour. As wild as one's imagination and enthusiasm might have been, it would have been inconceivable that exactly 60 years later humans would fly to the moon and back.

Electricity's unique role

Electricity lies at the heart of the global quest for sustainability for several reasons. It is the prerequisite for the networked world of the future. It will be the enabling foundation of new digital technology and the vehicle on which most future productivity gains in industry, business, and commerce will depend. And to the surprise of many, it will remain the best pathway to resource efficiency, quality of life, and pollution control.

In fact, the National Academy of Engineering just voted the "vast network of electrification" the single greatest engineering achievement of the twentieth century by virtue of its ability to improve people's quality of life. It came out ahead of the automobile, the airplane, the computer, and even health care in its impact on society. The electricity grids of North America, Europe, and Japan are said to be the most complex machines ever built. Although they are not yet full networks—that is, not every node is connected to every other node—these networks have been sufficiently interconnected to become the central enabling technology of the global economy. They will have to be even more interconnected and complex to keep pace with the microprocessors and digital networks they power.

In the developed world, electricity has become almost a transparent technology, lost in the excitement surrounding its latest progeny—electronics, computers, the Internet, and so forth. Still, its role should be as profound in this century as it was in the last. "How and in what form global electrification goes forward in the next 50 years will determine, as much as anything, how we resolve the global 'trilemma' posed by population, poverty, and pollution," says Kurt Yeager, president and CEO of EPRI. "This trilemma is destined to become a defining issue of the twenty-first century."

Chauncey Starr, EPRI's founder, has captured the strong historical correlation between access to electricity, economic prosperity, and social choices. A large majority of the world's population is now trapped at a low economic level, where the focus of everyday life is on survival and on acquiring the basics now taken for granted in developed nations. As Starr shows, only after electricity consumption reaches a threshold of approximately 1000 kWh per capita do people turn their attention from the basics of immediate survival to the level of "amenities," including education, the environment, and intergenerational investment. Given the chicken-and-egg nature of the process of social advancement, it is not possible to point to electricity as the initial spark, but it is fair to say that economic development does not happen today without electricity.

Electricity has been extended to more than 1.3 billion people over the past 25 years, with leveraged economic impact. In South Africa, for example, 10 to 20 new businesses are started for every 100 homes that are electrified. Electricity frees up human labor—reducing the time people spend in such marginal daily tasks as carrying water and wood—and provides light in the evening for reading and studying. These simple basics can become the stepping stones to a better life and a doorway to the global economy. Because electricity can be effectively produced from a wide variety of local energy sources and because it is so precise at the point of use, it is the ideal energy carrier for economic and social development. Distributed electricity generation can be used to achieve basic rural electrification goals in the developing world, thereby helping to counteract the trend toward massive urbanization. People in rural areas and villages need to have access to the opportunities and jobs that are now attainable only by migrating to large cities.

Electrification should also help with efforts to improve deteriorating urban air quality in the growing megacities of the world. Mortality from respiratory infections may be as much as five times higher in developing countries than in developed countries. The health costs can be debilitating; it is estimated, for example, that the total health cost of air emissions in Cairo alone now exceeds $1 billion per year.

How global electrification proceeds—on a large or a small scale, with clean or dirty technology—will influence the planet socially, economically, and environmentally for centuries. Ultimately, our success or failure in this endeavor will bear heavily on whether we can effectively handle the issues of the habitability and biodiversity of the planet.

Ironically, electricity may also become the focal point for growing animosity in the coming century, for the simple reason that it is taking on more and more responsibility for society's energy-related pollution. Electricity accounted for only about 25% of the world's energy consumption in 1970. Today, in the developed countries, its share of energy consumption is nearly 40%, and by 2050 that figure may reach 60–70%. If transportation is fully electrified through fuel cells,

Sustainability R&D Targets for 2050

Technology Area	Targets
Infrastructure	Ensure universal availability of fresh water, sanitation, commercial energy, and communications. Provide streamlined infrastructure technology for worldwide urban use.
Electrification	Achieve universal global electrification, including at least basic electricity service of about 1000 kWh per person per year.
Energy intensity	Accelerate the decline in energy intensity, from a rate of 1% per year to 2% per year.
Energy efficiency	Double the efficiency of the entire energy chain, from 5% to 10%.
Decarbonization	Triple the rate of the decarbonization of global energy, from 0.3% per year to 1.0% per year, by 2030 and maintain that rate.
Land use	Increase global average grain yields by 2% per year, and return at least one-fourth of global cropland to a natural state or to managed use.
Water use	Cut agricultural and industrial water use in half.
Transportation	Electrify over 50% of global transportation.
Industrial ecology	Reduce industrial waste streams to near zero, and minimize the need for virgin resources.
Education	Provide universal access to education and technical training.

hybrids, and the like, electricity's energy share could climb even higher. This growth accentuates the need to ensure that future electricity generation and use are as clean and efficient as possible and that best practices and technologies are available to developing countries as well as affluent ones. Fortunately for the world, electricity has the greatest potential of all the energy forms to deliver in the area of environmental stewardship.

Roadmap's call to action

The Electricity Technology Roadmap Initiative, which was launched by EPRI in 1998, began by bringing representatives of more than 150 diverse organizations together in a series of workshops and meetings to explore ways to enhance the future value of electricity to society. They staked out some ambitious destinations through time, leading to the ultimate destination of "managing global sustainability." They also established some specific goals to ensure that the tools will be in hand by 2025 to reach various sustainability targets, including universal global electrification, by midcentury. Among these goals are the acceleration of electricity-based innovation and R&D and the benchmarking of our progress toward sustainability.

Universal global electrification means bringing everyone in the world to at least the "amenities" level defined by Starr. At this level, it becomes more likely that the rich and poor nations will find common ground for pursuing sustainability policies. The roadmap stakeholders are calling for a bare minimum of 1000 kWh per person per year to be available by 2050. This would raise the *average* in today's developing countries to around 3000 kWh per person per year in 2050, just above the level in the United States a century earlier, around 1950.

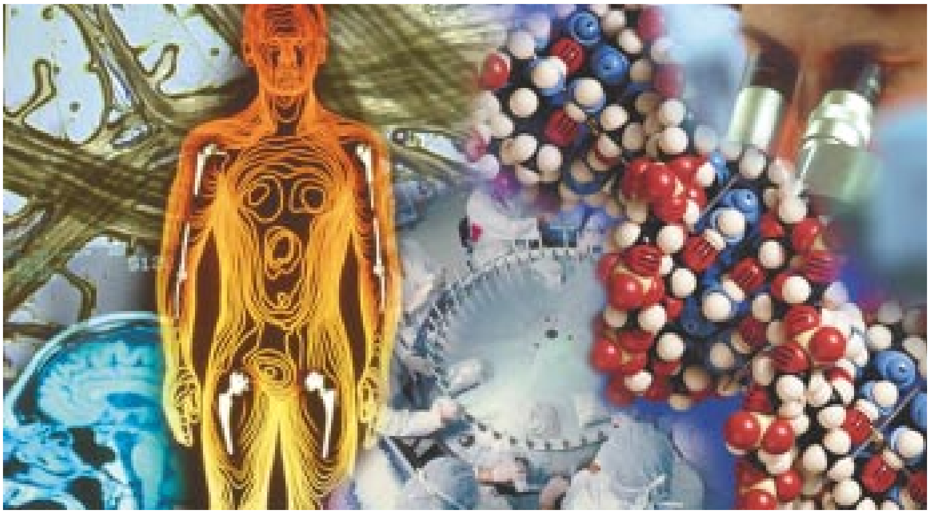
Moreover, projections suggest that it will be possible to reduce the energy intensity of economic growth by at least 50% over the next 50 years through universal electrification, with about half the reduction resulting from end-use efficiency improvements. Consequently, the 3000 kWh of 2050 will go much further in powering applications—lighting, space conditioning, industrial processes, computing, communications, and the like—than an equivalent amount of electric energy used in the United States in 1950. Already, for example, the manufacturing and widespread application of compact fluorescent lightbulbs has become a priority in China for reasons of both energy efficiency and export potential.

Even with the large efficiency improvements that are anticipated in electricity generation and end use, building enough capacity to supply 9–10 billion people with power will be an enormous challenge. Total global generating capacity requirements for 2050 could reach a daunting 10,000 GW—the equivalent of bringing on-line a 1000-MW power plant somewhere in the world every two days for the next 50 years. This is a tall order, and achieving it affordably and with minimal environmental impacts will require an unusual degree of dedicated R&D, supported through public and private collaboration, to accelerate the current pace of technological development.

According to the roadmap stakeholders, reaching the destinations that they have defined calls for at least an additional $4 billion per year in electricity-related R&D by the United States alone. One of the key destinations, resolution of the energy-environment conflict, would in itself require an additional $2 billion per year in U.S. R&D over the next 10 years to speed up the development of clean power generation. This is more than double the nation's current level of funding in this area from both the public and private sectors.

The rate of innovation is especially critical to sustainability. The roadmap participants have concluded that a "2% solution" is needed to support a sustainable future. By this, they mean that productivity improvements in a range of areas—including global industrial processes, energy intensity, resource utilization, agricultural yield, emissions reduction, and water consumption—have to occur at a pace of 2% or more per year over the next century. If the advances are distributed on a global basis, this pace should be sufficient to keep the world ahead of growing social and environmental threats. It will also generate the global wealth necessary to progressively eliminate the root cause of these threats and will provide the means to cope with the inevitable surprises that will arise. For example, a 2% annual increase in global electricity supply, if made broadly available in developing countries, would meet the goal of providing 1000 kWh per year to every person in the world in 2050. This means extending the benefits of electricity to 100 million new users every year.

Maintaining a 2% pace in productivity improvements for a century will be formidable. It is in line with the cumulative advancement in the United States during the twentieth century, but at least twice the



Biology may provide some of the most important technologies for sustainability in the next century, resulting in genetically engineered supercrops, advanced medicines and health treatments, and solutions to carbon sequestration and other environmental problems.

world average over that period. The disparity has been particularly great in the past 25 years, as population growth has outstripped economic development in many parts of the world. The result has been massive borrowing to maintain or enhance short-term standards of living. Staying ahead of population-related challenges is now in the enlightened self-interest of all the world's peoples, and the 2% solution offers a benchmark for success. Sustaining efficiency gains of 2% per year throughout the twenty-first century would allow essential global economic development to continue while sparing the planet. This pace, for example, should help stabilize world population (to the extent that wealth is a primary determinant of population growth), limit atmospheric levels of greenhouse gases to below agreed-upon strategic limits, provide sufficient food for the bulk of the world's people (as well as the wherewithal to buy it), and return significant amounts of land and water to their natural states.

Roadmap participants envision technology and the spread of liberal capitalism as powerful agents for the 2% solution in that they can stimulate global development and foster worldwide participation in market economies. However, the participants have also expressed some concern and caution about unbridled globalization overrunning local cultures and societies and creating instability, unrest, and conflict. At its worst, globalization could lock weaker nations into commodity-production dependencies, leading to a survival-of-the-fittest global economy in which the rich get richer and most of the poor stay poor. Establishing greater dialogue and cooperation among developed and developing nations is therefore considered critical to ensuring that globalization delivers on its promise to be a vehicle of worldwide progress that honors the diversity of nations and peoples.

Targets of sustainability

There is no single measure of sustainability; rather, it will require continued progress in a wide variety of areas that reflect the growing efficiency of resource utilization, broad improvements in the quality of life for today's impoverished people, and acceleration of the historical shift away from resource-intensive economic activity. The roadmap's sustainability R&D targets provide a first-order approximation of what will be required. In many cases, the targets represent a significant stretch beyond today's levels, but they are all technologically achievable. The roadmap sets an optimistic course, certain that with accelerated R&D and a much stronger technological foundation in hand by 2025, the world could be well on a path to economic and environmental sustainability by midcentury. The goals for sustainability are simply too far-reaching to be achieved solely through governmental directives or policy. Rather, they will be reached most readily via a healthy, robust global economy in which accelerated technological innovation in the private sector is strongly encouraged and supported by public policy.

The challenges of bringing the world to a state of economic and environmental sustainability in the coming century are immense but not insurmountable. Technology is on the threshold of profound change, quite likely to be broader, faster, and more dramatic in its impact than that which we experienced in the twentieth century. Fortunately, the impact appears to be heading in the right direction. Much of the leading-edge technology is environmentally friendly and, from today's vantage point, is likely to lead to a global economy that is cleaner, leaner, lighter, and drier; many times more efficient, productive, and abundant; and altogether less invasive and less destructive of the natural world.

History teaches us that technology can be a liberating force for humanity, allowing us to break through our own self-made limits as well as those posed by the natural world. The next steps will be to extend the benefits of innovation to the billions of people without access and, in the words of Jesse Ausubel, to begin "liberating the environment itself." This entails meeting our needs with far fewer resources by developing a "hydrogen economy, landless agriculture, and industrial ecosystems in which waste virtually disappears . . . and by broadening our notions of democracy, as well as our view of the ethical standing of trees, owls, and mountains." In many ways, the material abundance and extended human capabilities generated through hundreds of years of technology development have led us to a new understanding and heightened respect for the underlying "technologies of life." Offering four billion years of experience, nature will become one of our best teachers in the new century; we are likely to see new technology progressively taking on the character and attributes of living systems. Technology may even begin to disappear into the landscape as microminiaturization and biological design ensue.

Still, though technology is heading in the right direction, what remains principally in question is whether the pace of innovation is adequate to stay ahead of the curve of global problems and whether new advances in technology can be quickly brought down in cost and readily distributed throughout the world. Can we achieve the 2% solution of progressive improvement in economic productivity, land and water use, recycling, emissions reduction, and agricultural yield, year after year, decade after decade, in nation after nation? It's a formidable challenge, but with better tools we just might be able to pull it off. If so, the key to success will not be found in one small corner of the world. The challenge will be met by making the basic building blocks of innovation—education, R&D, infrastructure, and law—available in full measure to future generations everywhere in the world. That future begins now. ■

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The Value of Greenhouse Gas Emissions Trading

The Story in Brief The trading of carbon dioxide and other greenhouse gas emissions permits is likely to become an important part of any coordinated international response to global climate change. While trading is recognized as a key to lowering the costs of limiting global emissions, the details regarding which countries might buy or sell emissions permits and under what circumstances have remained unclear. Now, in several groundbreaking studies focused on carbon markets, researchers have developed a simplified approach to analyzing outcomes—an approach that not only quantifies the impacts of various trading conditions but also helps policymakers interpret who would trade and how specific nations would be affected. The results indicate that trading would indeed substantially lower the overall costs of reducing carbon emissions, and that as the market becomes broader and less constrained, the savings grow.

by Taylor Moore

The 1992 United Nations Framework Convention on Climate Change stated as its ultimate objective the "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system." To meet the stabilization targets under consideration, substantial reductions of global greenhouse gas emissions from human activities will ultimately be required. Although the Framework Convention did not identify a specific target level for atmospheric greenhouse gases, it did establish as a basic principle that policies and measures to deal with climate change should be cost-effective to ensure global benefits at the lowest possible cost.

After several years of negotiations, the 1997 Kyoto Protocol to the Framework Convention set—for the first time—targets and timetables for reducing carbon dioxide and other greenhouse gas emissions in industrialized countries and in countries with economies in transition. (Together these are referred to as Annex B countries because they are specified in Annex B of the protocol.) The intended net result of these commitments was to reduce emissions from Annex B countries by an average of 5% from 1990 baseline levels in the period 2008–2012.

Although the protocol has yet to be ratified, the so-called Kyoto mechanisms have attracted substantial attention as policy instruments. These mechanisms seek to pro-

PHOTO COLLAGE BY MARTHA LOVETTE

vide economically efficient approaches for achieving emissions reduction goals by allowing various forms of emissions trading—between and within Annex B countries as well as between Annex B countries and developing countries.

Regardless of the fate of the Kyoto Protocol itself, some form of emissions trading is likely to be incorporated in any international climate change agreement. Indeed, there is widespread acknowledgment in the policy analysis community that the costs of achieving reductions in global greenhouse gas emissions would be dramatically lower with emissions trading than under a no-trading alternative; this is particularly true with full global trading, in which all countries are involved.

Two types of international trading are envisioned. One is the trading of target amounts between countries with assigned targets—the Annex B countries. The other, which includes countries without assigned targets, is the trading of credits for specific emissions-reducing projects.

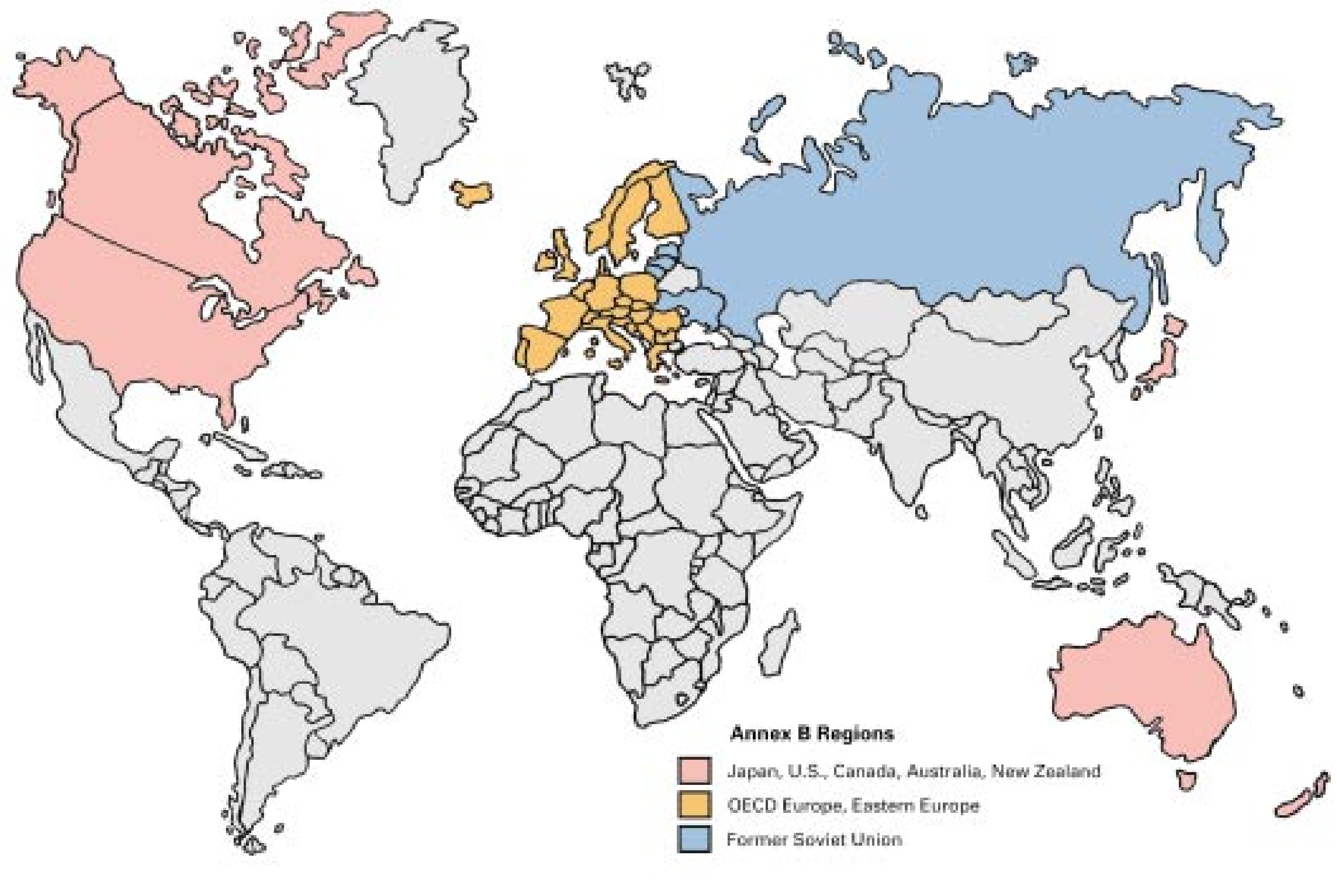
Under the first type of trading, Annex B countries able to meet their CO_2 emissions reduction targets at relatively low cost could sell emissions rights—in the form of carbon permits—to Annex B countries that face higher costs in meeting their targets. Also, trading could take place within Annex B countries between companies or other groups with allocated permits; or such groups could participate in permit trading in an international market.

In the second type of trading, discussions center on the so-called Clean Development Mechanism (CDM), which addresses the possible nonparticipation in emissions limits or reduction commitments by developing countries like China and India, whose carbon emissions are increasing much faster than those of developed countries.

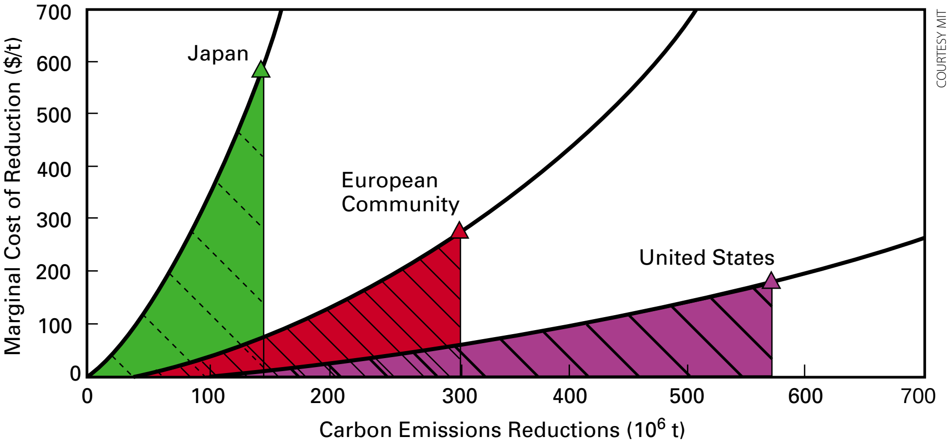
The CDM allows non–Annex B countries to develop mitigation credits—beginning as early as this year—through sustainable development activities. In exchange for investments that support these activities, Annex B countries would receive credits to help them achieve compliance with their quantified emissions limits and reduction commitments. A related mechanism in the protocol known as Joint Implementation (JI) allows Annex B countries to claim credits for lower-cost emissions reduction activities in other Annex B countries—credits that can be used to offset their own, costlier-to-reduce, emissions.

Clarifying the costs

Current negotiations on emissions trading are likely to set precedents for future international climate policy. As the economic and political discussions evolve, EPRI is making significant contributions toward

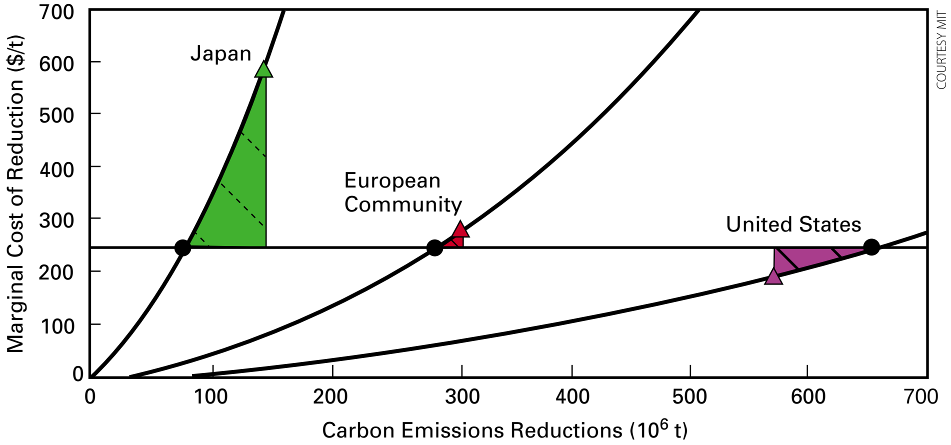


Carbon emissions trading is expected to occur initially between or within the so-called Annex B countries—the developed countries and countries in economic transition that have made commitments to reduce greenhouse gas emissions under the Kyoto Protocol. To analyze the potential extent and impacts of emissions permit trading, the countries are often grouped into three regions: Japan, the United States, Canada, Australia, and New Zealand; participating Western and Eastern European countries; and participating states of the former Soviet Union.



COURTESY MIT

MIT researchers ran an economic model to estimate costs to the three major OECD regions—Japan, the European Community (EC), and the United States—of meeting their carbon emissions reduction commitments in 2010 under the Kyoto Protocol. The researchers then used the results to produce these marginal abatement curves, which show how much it would cost, at various levels of abatement, to achieve an additional reduction of 1 ton of carbon. The triangle on each curve indicates the reduction the region must make to meet its 2010 commitment; the hatched area equals the total cost of making that reduction. The curves show that the marginal cost—the cost of cutting another ton of carbon—increases as the total emissions reduction increases.



COURTESY MIT

According to the MIT marginal abatement curves, Japan and the EC would pay more per ton of carbon emissions reduction than the United States to meet their commitments (triangles) under the Kyoto Protocol. With emissions trading, Japan and the EC would pay the United States to make some reductions for them; as a result, the U.S. marginal cost would rise, and the marginal costs for the other two regions would fall. When the costs reached the same level ($240 per ton), trading would cease. The actual abatement levels with trading (bullets) would translate into cost savings for Japan and the EC and earnings for the United States (hatched areas). Under the assumptions of this example, emissions trading would reduce the direct costs of meeting the 2010 Kyoto Protocol commitments for these regions by a total of $13 billion.

clarifying both the potential costs of implementing the Kyoto Protocol and the potential benefits of emissions trading. EPRI experts were among the early proponents of trading and of the need to include developing countries to minimize global emissions reduction costs.

EPRI also sponsors the Stanford Energy Modeling Forum, which brings together many top economic modeling experts from around the world and has recently produced a comprehensive series of comparative analyses of the economic and energy sector impacts of the Kyoto Protocol. Other forum sponsors are the U.S. Department of Energy, the U.S. Environmental Protection Agency, Mitsubishi Corporation, the New Energy and Industrial Technology Development Organization of Japan, and about 20 other corporate affiliates.

In addition to supporting the Stanford forum, EPRI has joined with more than two dozen global energy and industrial firms and government agencies in sponsoring the Massachusetts Institute of Technology's Joint Program on the Science and Policy of Global Change. Managed by the school's Center for Global Change Science and Center for Energy and Environmental Policy Research, the program has emerged as a leader in improving understanding of the scientific, economic, and ecological aspects of climate change. It is producing policy assessments that directly serve the needs of ongoing national and international discussions.

Both the Stanford Energy Modeling Forum and the MIT Joint Program on the Science and Policy of Global Change are helping identify key policy-relevant insights about the economic impact and value of emissions trading and implementation flexibility.

Economic growth is an important determinant of the cost or difficulty of meeting emissions limits. For example, if the U.S. economy grows rapidly, it becomes more difficult and costly to meet targets despite the availability of options for reducing emissions. The U.S. commitment under the Kyoto Protocol is to reduce emissions by 7% from 1990 levels. However, given actual and anticipated economic growth and assuming no carbon constraints, by 2010 emissions could be as much as 30% above the 1990 baseline levels.

Reducing CO_2 emissions is easier and less costly for some countries than for others because of differences in economic structure, resource availability, and existing energy efficiency levels. Even in similarly efficient developed countries, the cost of preventing 1 ton of atmospheric carbon loading—equivalent to preventing 3.67 tons of CO_2 emissions—varies considerably. Emissions trading enlists market-driven economic forces to make the least-expensive reductions available and thus minimize the total cost of complying with emissions constraints.

There is growing consensus among economists that such trading may be a key element for ultimately stabilizing atmospheric concentrations of CO_2 at an acceptable societal cost. Unlike the case with some other pollutants, it makes little difference where greenhouse gases are actually emitted, because they are well mixed and remain in the atmosphere for decades to centuries. Many analysts point to the U.S. success with sulfur dioxide emissions trading, which has saved electric utilities and consumers as much as 30% of the originally estimated cost of reducing SO_2 emissions from power plants.

Yet international agreement on acceptable rules for greenhouse gas emissions trading remains problematic—indeed the subject of trading remains controversial—in part because the potential impacts are complex. Moreover, conducting, monitoring, verifying, and enforcing an international system for trading greenhouse gases would be orders of magnitude more complicated than administering a trading system for emissions of a single type, from a limited number of sources, in a single country. "The global dimensions of the issue raise institutional and enforcement questions that current international law is ill suited to resolve," points out Tom Wilson, a climate change program manager in EPRI's Science and Technology Development Division.

"The ubiquitous nature of greenhouse gas emissions and sinks complicates matters by making national emissions inventories difficult to estimate and by making project-based credits a challenge to quantify," Wilson says. "Analyses have revealed several key elements in controlling costs—elements that are critical to any climate agreement. One is 'when' flexibility, or flexibility in the timing of reduction efforts. Another is 'where' flexibility, the flexibility to make reductions in the places where it is most cost-effective to do so. Although the current context for discussions—the Kyoto Protocol—is short term, focusing on an initial five-year period, it does provide a structure for discussing 'where' flexibility via emissions trading."

Simplifying the analysis of potential savings

In work sponsored in part by EPRI, MIT researchers led by A. Denny Ellerman—a senior lecturer in the Sloan School of Management and the executive director of the Joint Program on the Science and Policy of Global Change—have developed a simplified approach to analyzing CO_2 emissions trading. This approach quantifies the impacts of various trading conditions and, more important, helps policymakers interpret who would trade and how specific nations would be affected.

Ellerman and his colleagues used multiple outputs from a sophisticated computer model developed by others at MIT. The model simulates economic activity, energy use, and greenhouse gas emissions for many regions and economic sectors in order to forecast carbon emissions and compute the costs of reducing them. Model cost estimates for reducing carbon levels in a region by specific amounts in a specific year are combined to form a marginal abatement curve, showing the cost of an additional 1-ton reduction in carbon emissions at various levels of abatement. As expected, within each region the cost of reducing a ton of carbon emissions increases as more reduction occurs.

But as the MIT work makes clear, the cost of reducing emissions by a set amount differs substantially from region to region. Take, for example, the researchers' analysis of the three major regions of the Organization for Economic Cooperation and Development (OECD): Japan, the United States, and the European Community (EC), the predecessor of the European Union. Both the marginal cost and the total cost of abatement are higher in Japan than in the United States or the EC for equal percentage reductions from the business-as-usual baseline. The reasons are the Japanese economy's greater energy efficiency and the relatively low amounts of CO_2 attributable to electricity generation there. The researchers have identified the ability to switch from coal to natural gas as the key determinant of cost in the short term; countries that, like Japan, use little coal and do not have low-cost natural gas face the highest costs.

The curves also strikingly reveal the variations in marginal abatement cost as each region approaches its constraint, or required level of abatement. At that level, the marginal cost is lower in the United States than in either Japan or the EC, even though the number of tons reduced is higher in the United States. Thus, if emissions trading were limited to these three regions, Japan and the EC could save money by paying the United States to reduce on their behalf.

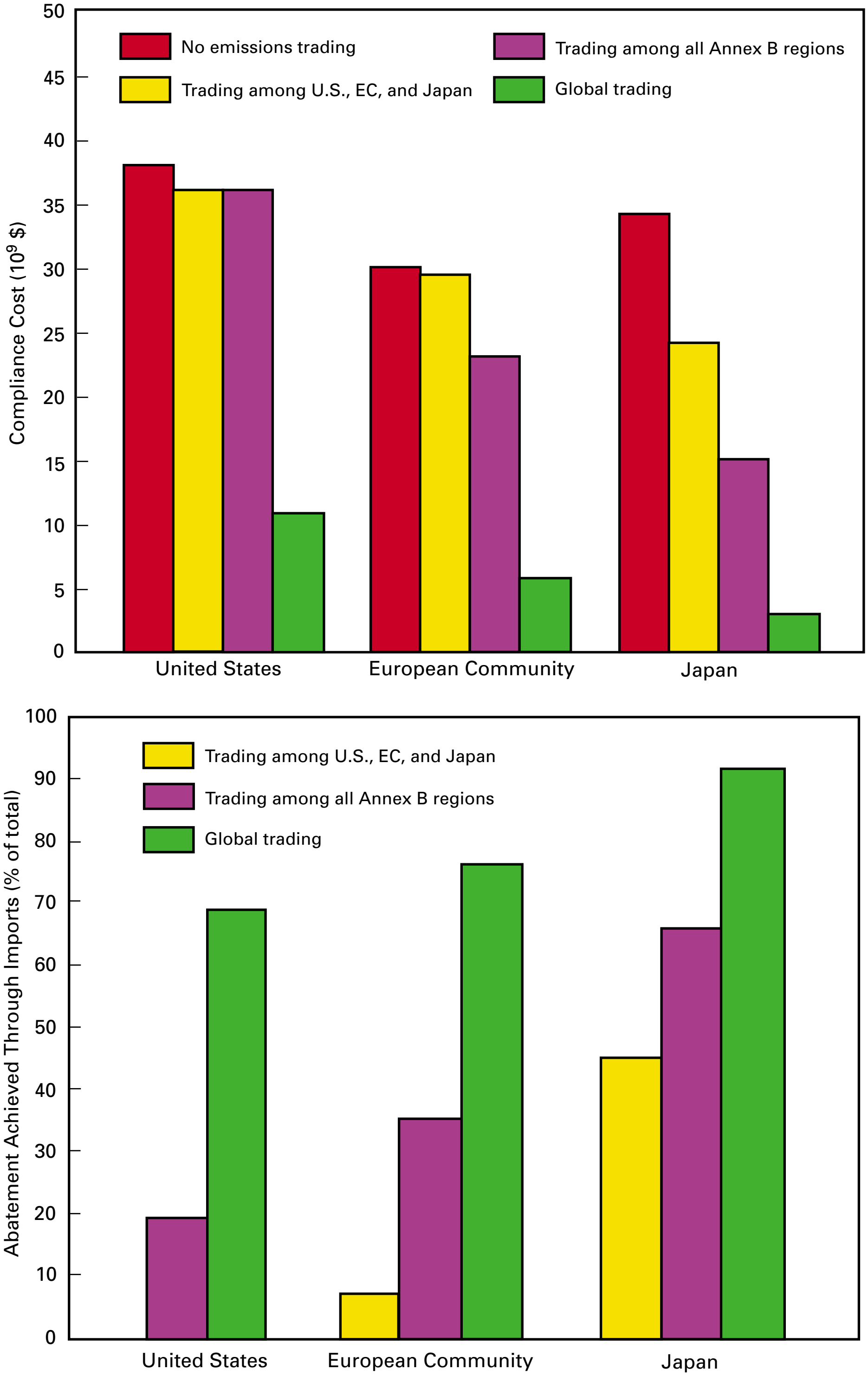
In this simple hypothetical illustration, the United States becomes an exporter of emissions permits because it faces the lowest marginal cost. But the amount of abatement it is likely to export is limited by economics, since as it reduces more, the per-ton cost of reduction increases. As Japan and the EC reduce less, their per-ton costs of reduction gradually decline. At some point the marginal cost in the United States will equal the marginal costs in Japan and the EC, and in the absence of cheaper abatement from the United States, Japan and the EC will perform the balance of their required reductions themselves.

Given the assumptions in this example, when the reduction costs for all participants converge, trading is no longer beneficial, but the United States has abated more than required while Japan and the EC have abated less than required. All three regions can meet their obligations for a total cost that is several billion dollars less in 2010 than they would have had to spend if trading had not been allowed.

"These results demonstrate several important points," Ellerman remarks. "First, even if only the three major OECD regions trade, their cumulative savings are significant. Second, although all regions benefit to some extent, the gains from trade are greatest for those regions whose marginal cost without trading is furthest from the market price of emissions permits. Finally, when trading occurs, the disparity among countries in the cost burden of achieving their commitments is diminished—a condition that encourages adherence to the commitments and the subsequent upholding of the agreement."

The picture regarding buyers and sellers changes significantly when the countries of all Annex B regions participate in emissions trading, largely because of the situation in Russia and other states of the former Soviet Union (FSU). Most analysts predict that the Kyoto commitments of the FSU countries will not constrain their carbon emissions in 2010; that is, given the decline in the region's economic output since the dissolution of the Soviet Union, the level of emissions in 2010 is now expected to be lower than the level allowed under the commitments.

The difference between the committed level and the predicted level translates into emissions permits that the FSU countries could sell. (This is sometimes referred to as "hot air" because no actual reductions are expected to occur during the protocol's first commitment period.) Meanwhile, a marginal abatement curve for the FSU suggests that the achievement of a certain level of abatement in order to export permits would make economic sense, according to Ellerman.



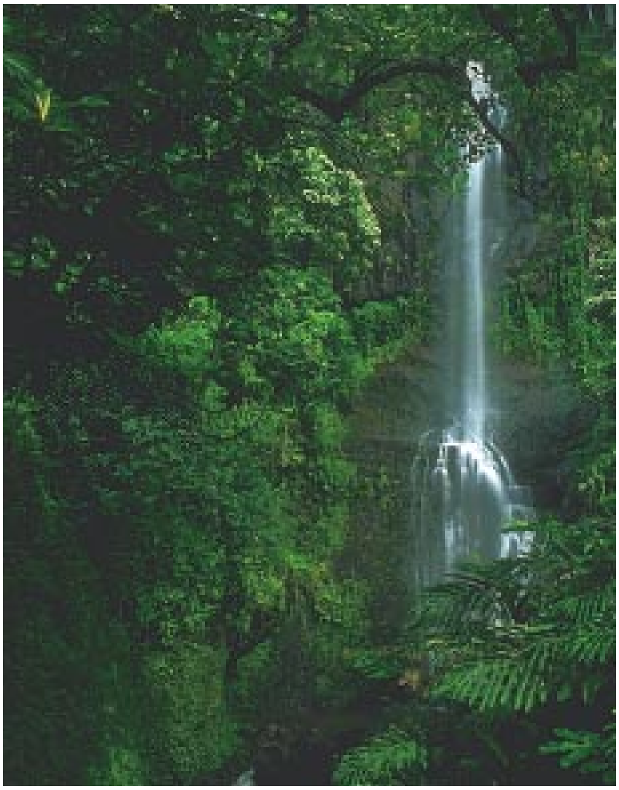
MIT's analysis shows that the costs of meeting the Kyoto Protocol's 2010 carbon emissions reduction commitments drop considerably as the pool of trading participants expands. With all Annex B regions trading, the United States, the EC, and Japan are each projected to achieve a substantial percentage of their abatement through the purchase of emissions permits. If the non–Annex B countries were to accept commitment targets—allowing true global trading—the total direct costs of compliance for the Annex B regions could drop by as much as 90%.

By creating marginal abatement curves for all the Annex B regions, the MIT researchers determined which regions would buy and sell carbon emissions permits and how costs would change. With all the Annex B regions trading, the projected market price of emissions permits settles at $127 per ton in 2010 under a Kyoto scenario—well below the $240 per ton when only the three OECD regions trade. At that permit price, the United States becomes an importer rather than an exporter, and Japan and the EC increase the fraction of reduction requirements met with imports. Japan again reaps the largest economic benefit of the OECD regions, saving $19 billion in 2010 by trading. The biggest winners, however, are the major states of the FSU; by providing 98% of all exports (through "hot air" and actual low-cost reductions), they could earn a total of $34 billion annually.

Opening the door to global trading

Broadening the CO_2 trading market to non–Annex B regions around the world has the potential to bring in many more low-cost abatement providers, notably China and India. Because of the generally less-efficient use of energy and less-efficient energy delivery infrastructure in developing countries, more low-cost opportunities for reducing carbon emissions exist there than in developed countries. And in developing countries that, like China and India, have no emissions constraints and are rapidly growing, there are many more options available than retrofits of existing facilities.

Although the potential savings from global trading are large, the only way currently under discussion to get such low-cost abatements on the market is through the CDM on a project-by-project basis. Agreement has not yet been reached on various fundamental factors that would affect the cost of buying these reductions, including how the CDM would operate and what scope of projects would be allowed. MIT's analysis of the economic behavior of all participants indicates that, with global trading, the market price of permits drops to $24 per ton in 2010. Few of these potential reductions are likely to be transacted over the next decade, however, and the CDM's administrative and other costs would probably increase the price of the reductions significantly.


Although developing countries did not make emissions reduction commitments under the Kyoto Protocol, the treaty established the Clean Development Mechanism, or CDM, by which non–Annex B countries may earn emissions mitigation credits through sustainable development activities. The types of projects allowable are currently under negotiation but may eventually include activities like rain forest preservation and reforestation. The mitigation credits could be sold to Annex B countries to help them achieve their reduction commitments at lower cost.

The MIT researchers also calculated the total costs of implementing the Kyoto Protocol for all Annex B regions. Without trading, the cost to the Annex B regions is $120 billion in 2010. When trading occurs but is limited to the Annex B regions, the cost drops to $54 billion. If nations worldwide participated fully in a trading program, the total cost of achieving the Kyoto goals could be reduced substantially, but there is currently no framework under discussion that would allow this level of savings to be achieved.

"These findings shed light on a frequently heard argument—that the gains from trading will be limited because only developed nations will trade," Ellerman points out. "Concerns that potential suppliers of low-cost permits may not trade are valid. Some developing nations may not participate because their governments are unfamiliar with trading as a concept; China and India have objected to emissions trading on principle; and some negotiators are demanding that the FSU countries have stricter abatement constraints so that they cannot sell emissions permits without making real reductions.

However, Ellerman says, "our studies suggest that even a subset of traders can make a significant difference. A wider market brings lower-cost permits, greater benefits to the constrained regions, and lower costs. The wider the market, the better; but even a narrow market is better than none at all."

As with all modeling, the outcomes of the MIT analysis are highly dependent on base assumptions, including those related to the economic growth of individual countries. For example, if the United States experiences more-rapid economic growth than Japan or the EC, as a recent U.S. Energy Information Administration forecast suggests, the United States would face the highest marginal cost and would therefore import permits from Japan and the EC.

The MIT researchers also examined the possible impacts of various proposed trading rules. One proposal made by the European nations and rejected by the United States involves a ceiling on the extent to which a single country can meet its commitment by buying emissions permits from other countries. Analyses using marginal abatement curves suggest that the imposition of such a ceiling would have adverse impacts, increasing the global cost of meeting the Kyoto requirements and transferring most of the trading gains from exporters to importers.

Concludes Ellerman, "Marginal abatement curves are proving to be a useful tool for investigating not only economic uncertainties but also proposed policy options and their potential impacts on the magnitude and distribution of gains from emissions trading."

The multimodel approach

The MIT results amplify and extend the findings of a Stanford Energy Modeling Forum study in which a variety of economic models predicted that the gains from emissions trading could be substantial and would grow as the market became broader and less constrained. The results of the forum's multimodel evaluation of the Kyoto Protocol were presented in detail last year in a special issue of *The Energy Journal,* published by the International Association for Energy Economics.

In the Stanford forum study, each of 13 modeling teams in Australia, Britain, Japan, the Netherlands, and the United States used its own model to conduct simulations of various aspects of implementing the Kyoto Protocol, including emissions trading and the CDM. The study's objectives were to identify findings and insights that were robust across a wide range of models, to explain the differences in results from the various models, and to identify high-priority areas for future research.

The 13 models used ranged from highly aggregated models of the world economy and global trade to detail-oriented process models focusing on the energy sector. The latter type considers fossil fuel supply and consumption, renewable energy resources, power generation technologies, energy prices, and transitions to future technologies; an example is the MIT model whose output was used by Ellerman and his associates in the analysis described earlier.

The modeling teams were asked to run three types of scenario. The first type, a reference scenario, used modeler-chosen values for gross domestic product, population, energy prices, and the like and assumed that no new policies resulted from the Kyoto Protocol. The second and third scenario types were designed to explore "where" and "when" flexibility—that is, in what parts of the world and on what timescale reductions are pursued.

To explore "where" flexibility, the teams ran a number of stylized Kyoto scenarios in which three factors were varied: the amount of international emissions trading assumed; the availability of carbon sinks, and of reductions of greenhouse gas emissions other than CO_2, to satisfy the protocol's requirements; and the required emissions reduction beyond 2010. To probe "when" flexibility, the modelers ran two cost-minimizing scenarios. In one, the protocol's targets were followed through 2010, and then the additional cost of limiting the atmospheric CO_2 concentration to 550 parts per million (by volume) was minimized. In the other, minimizing the cost of limiting the CO_2 concentration to 550 ppm was the controlling objective throughout, with no observance of the targets proposed in the Kyoto Protocol.

To get a rough idea of what is at stake in the determination of rules for carbon emissions trading, the forum study evaluated some relatively simple implementations of the protocol's trading provisions. The results gave a wide range of estimates that reflected not only the differences in assumptions about how the agreement would be implemented but also differences in the structures of the models used to make the cost projections.

Still, writing in the overview of the special *Energy Journal* issue, Stanford University's John Weyant and Jennifer Hill were able to draw several common conclusions from the comparative analyses: "First, meeting the requirements of the Kyoto Protocol will not stop economic growth anywhere in the world, but it will not be free either. In most [Annex B] countries, significant adjustments will need to be undertaken and costs will need to be paid. Second, unless care is taken to prevent it, sellers of international emissions rights . . . may be able to exercise market power, raising the cost of the protocol to the other [Annex B] countries.*

"Third, meaningful global trading probably requires that the [non–Annex B] countries take on emissions targets; without them, accounting and monitoring . . . become almost impossible. Finally, it appears that the emissions trajectory prescribed in the Kyoto Protocol is neither optimal in balancing the costs and benefits of climate change mitigation nor cost-effective in leading to stabilization of the concentration of carbon dioxide at any level above about 500 parts per million by volume."

The challenge ahead

The potential for emissions trading to reduce the costs of meeting environmental goals is clear from past experience with domestic trading systems and from cost analyses based on a wide variety of models and input assumptions. "Realizing these potential savings is the challenge," says EPRI's Wilson. "Political decisions currently under discussion could place hard limits on the ability of countries to buy or to sell permits. With no clear picture of compliance mechanisms, there are additional discussions aimed at limiting emissions trading in order to reduce the possible degree of noncompliance.

"A wide range of issues are associated with project-based crediting. Although there are numerous precedents for providing environmental or economic credit on a project-by-project basis, creating workable, efficient rules for implementing the CDM will require reaching a fine balance between environmental integrity, economic efficiency, administrative efficiency, and income redistribution concerns."

In addition to the political issues that could limit trading, myriad institutional issues must be overcome, Wilson notes. "The challenge is to allow all parties and entities to participate in an efficient international market for reductions. If a country meets its domestic obligation through a carbon tax or efficiency standards, there need to be additional mechanisms for incentives to buy (such as by reducing the tax burden) or sell on the international market. Without institutions and rules that allow the least-expensive abatement measures to reach the global market or allow those parties with expensive reduction costs to buy in the market, the benefits of trade will be limited."

Last year, EPRI expanded its research on low-cost options for greenhouse gas reductions in order to begin addressing critical trading implementation issues. It plans to release—beginning this summer—a series of reports that will provide new insights into these issues. The first report in the series will describe precedents for project-based credits and will recommend key elements for a greenhouse gas credit program. A second report will analyze proposals to limit possible noncompliance through liability rules—rules that may assign some responsibility to the buyers of permits if the sellers do not comply with their targets.

"The goal is to provide insights that help create an environmentally effective, economically efficient trading system that will allow the nations of the world—if they agree to limit emissions—to reduce them at significantly lower and more evenly distributed cost," says Wilson. "These characteristics should make trading a key element of any future global climate agreement." ■

Further reading

Ellerman, A. D., and I. Sue Wing. *Supplementarity: An Invitation to Monopsony?* MIT Joint Program on the Science and Policy of Global Change Report No. 59. April 2000.

Weyant, J. P., ed. "The Costs of the Kyoto Protocol: A Multi-Model Evaluation." Special issue of *The Energy Journal,* 1999.

Ellerman, A. D., H. Jacoby, and A. Decaux. *The Effects of Developing Countries on the Kyoto Protocol and CO_2 Emissions Trading.* MIT Joint Program on the Science and Policy of Global Change Report No. 41. November 1998.

Ellerman, A. D., and A. Decaux. *Analysis of Post-Kyoto CO_2 Emissions Trading Using Marginal Abatement Curves.* MIT Joint Program on the Science and Policy of Global Change Report No. 40. October 1998.

Background information for this article was provided by Tom Wilson (twilson@epri.com). The MIT reports cited in the reading list above are available on-line at web.mit.edu/globalchange/www.

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*In general, the forum analyses were based on the countries listed in Annex I of the 1992 Framework Convention. While the list of countries in Annex B of the protocol varies slightly from that group, Weyant and Hill note that the results are approximately the same.

COURTESY PACIFIC GAS AND ELECTRIC

THE STORY IN BRIEF

What consequences might U.S. air emissions policies have in the first half of the twenty-first century? According to a new EPRI study, current and planned policies on sulfur dioxide, nitrogen oxides, and carbon dioxide would not allow sufficient time for the development and deployment of the technologies needed to make emissions reductions efficiently and could lead to an unsupportable reliance on natural gas–fired power generation over the next 20 years. A truly sustainable U.S. energy system will require a longer, more balanced transition—and accelerated technology R&D—to avoid unnecessary risks and disruptions.

E-EPIC Analyzing Emissions Policies

by Gordon Hester

THE 1990S WERE A DECADE OF monumental change in the electric power industry. Deregulation made electricity markets, beginning to be driven by competitive considerations, more diverse and dynamic. In addition, environmental concerns increasingly shaped fuel and technology decisions. As we enter the first decade of the new millennium, change will continue to be rapid, influenced by deregulation, competition, and environmental concerns. To meet environmental policy objectives, the electric power industry is already being called on to make greater reductions in emissions of sulfur dioxide (SO_2) and nitrogen oxides (NO_x) and to begin to reduce carbon dioxide (CO_2) emissions.

In anticipation of these changes, EPRI and others have conducted studies to address the potential economic and market effects of various environmental proposals, including the carbon emissions reductions called for in the 1997 Kyoto Protocol to the United Nations Framework Convention on Climate Change. In 1998, the U.S. Energy Information Administration (EIA) conducted one such investigation, using its National Energy Modeling System (NEMS). At the same time, EPRI began its Energy-Environment Policy Integration and Coordination (E-EPIC) study, using NEMS and other models to examine the potential effects of the future emissions restrictions outlined in proposed policies.

In the E-EPIC study, new SO_2, NO_x, and CO_2 emissions targets planned or proposed for implementation during the next decade were evaluated collectively as the Current Policy Direction, specified as follows. For SO_2, the study not only considered the power plant emissions cap set to begin in 2000—phase 2 of the Acid Rain Program under the 1990 Clean Air Act Amendments—but also assumed that additional reductions amounting to a 50% cut in that cap would occur in 2007. (These additional SO_2 reductions have been proposed in connection with new standards for particulate matter and regional haze.) For NO_x, the study assumed that summer emissions from power plants in 22 eastern states would be reduced to about 15% of 1990 levels, starting in 2003, to help meet ozone standards. Finally, although the Kyoto Protocol would require reducing U.S. carbon emissions (beginning in 2008) to 7% below the 1990 level, E-EPIC assumed that other measures, such as international emissions trading, would in fact allow a smaller net U.S. emissions reduction—to 9% *above* the 1990 level.

In other words, the study addressed the effects of a midrange carbon reduction, to be accomplished by imposing a tax on carbon emissions.

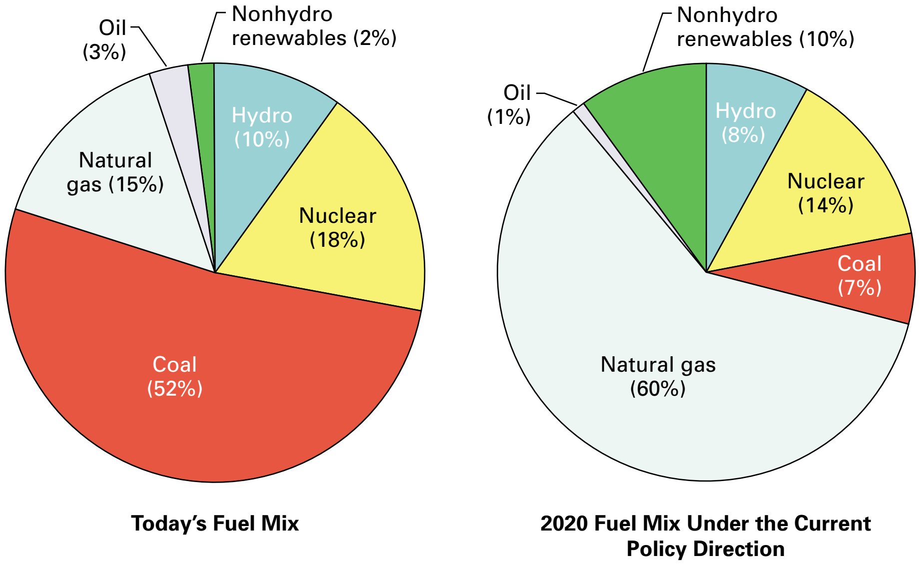
The E-EPIC study entailed an integrated analysis of U.S. electricity and gas supply and delivery systems, new end-use and power generation technologies, and associated energy resources and fuel markets. The study used EIA's well-documented NEMS software for integrated modeling capability. It also used an extended version of the NEMS Electricity Market Module, along with post-2020 energy-econometric modeling, to assess longer-term effects—to the year 2050. This examination of the post-2020 period was considered necessary both to account for the long lifetimes of power generation assets and energy infrastructures and to assess the role that advanced technologies must play in creating a sustainable and productive U.S. energy system.

According to the E-EPIC analysis, the Current Policy Direction would have a range of major effects on the U.S. energy system, consumers, and the economy. The projected impacts on the U.S. economy through 2020 are similar to those predicted by EIA in its study of the Kyoto Protocol. And E-EPIC's assessment of the technology and fuel changes that would be required beyond 2020 supports the broad conclusion that the Current Policy Direction would be economically and technically inefficient in implementing the proposed emissions reductions. The study found the timing of CO_2 reductions to be especially problematic.

Natural gas rules the near term

Coal-fired power plants form the backbone of the U.S. power generation system, currently providing about 52% of the nation's electricity. However, coal combustion is also the main focus of recent emissions proposals. According to E-EPIC, reductions of NO_x and SO_2 emissions would first be accomplished by retrofitting existing electric generating units—especially coal-fired units—with emissions control equipment and by increased fuel switching and greater reliance on existing and new natural gas–fired power plants. Since the NO_x and SO_2 control retrofits would not address the carbon problem, subsequent CO_2 emissions reduction requirements would lead to even larger shifts in fuel use, idling or retiring many coal-fired generating units.

Although renewable energy technologies are projected to expand considerably, the main CO_2 reduction strategy in the United States over the next 10 to 20 years would be the deployment of natural gas–fired power plants, with the most rapid capacity increase required by 2010. Under the Current Policy Direction, the natural gas share of electricity generation would rise from about 15% today to 60% by 2020. Meanwhile, coal's share of U.S. electricity generation would drop from over 50% to less than 10%, effectively forcing most of the country's coal infrastructure into disuse and reducing the diversity of the overall U.S. energy system fuel mix.



Today's Fuel Mix

2020 Fuel Mix Under the Current Policy Direction

According to E-EPIC analyses, the U.S. fuel mix for electricity generation would change dramatically over the next two decades under the Current Policy Direction. By 2020, the use of coal—today's dominant generation fuel—would shrink to around 7% while natural gas use would grow to a whopping 60%.

The rapid deployment of a new fleet of natural gas–fired plants would place additional stresses on the gas infrastructure. To fuel the new plants, U.S. natural gas production would have to increase 50% between now and 2010 and 70% by the year 2020. The gas exploration and production industry would have to increase drilling activity to roughly double the current levels, requiring a rapid reversal of its recent downsizing and staffing reductions. Many new drilling rigs would have to be constructed (1998 rig utilization approached 90%) and substantial new offshore fields developed—efforts requiring considerable lead time. Since 1949, gas deliverability has increased by over 1 trillion cubic feet (28 billion cubic meters) per year on only five occasions, but under the Current Policy Direction, growth would have to exceed 1.5 Tcf (42 billion cubic meters) in some years and would have to average more than 1 Tcf per year over a five-year span.

Stresses would extend beyond domestic natural gas production. Natural gas pipeline capacity would have to expand far faster than in recent times, requiring the construction of over 2000 miles (3200 kilometers) of pipeline per year between 2005 and 2009. This would pose serious challenges, even assuming no siting and permitting delays. The amount of gas-fired generating capacity added would reach just under 500 GW by 2020, only slightly less than all the fossil-fired generating capacity in place today. Meanwhile, Canada would presumably be seeking its own natural gas expansion to meet its carbon reduction targets, competing for North American gas supplies as well as for exploration, production, and pipeline construction capabilities.

The availability of new power generation hardware is also likely to be problematic, requiring a massive expansion of the specialized industry that manufactures gas turbine equipment. About 89% of the projected capacity additions between 2000 and 2010 will consist of simple-cycle or combined-cycle natural gas–fired combustion turbines. The global demand for new gas-fired turbines currently exceeds supply, with power generators vying for top spots on manufacturers' waiting lists. In the future, competition for gas-fired power generation hardware is likely to increase substantially, raising the price of this already-scarce equipment.

Under the Current Policy Direction, all of these components of natural gas infrastructure expansion must rapidly fall into place: exploration, production, delivery, and generation hardware. Given the difficulties in each area, there is considerable risk that infrastructure expansion would be inadequate to support CO_2 reduction targets and/or energy needs. Furthermore, the Current Policy Direction assumes the retention of considerable existing coal-fired generating capacity and a great expansion of generation from nonhydro renewables (primarily biomass and wind). Without this assumed capacity, which is uncertain, the gas infrastructure would have to expand even more.

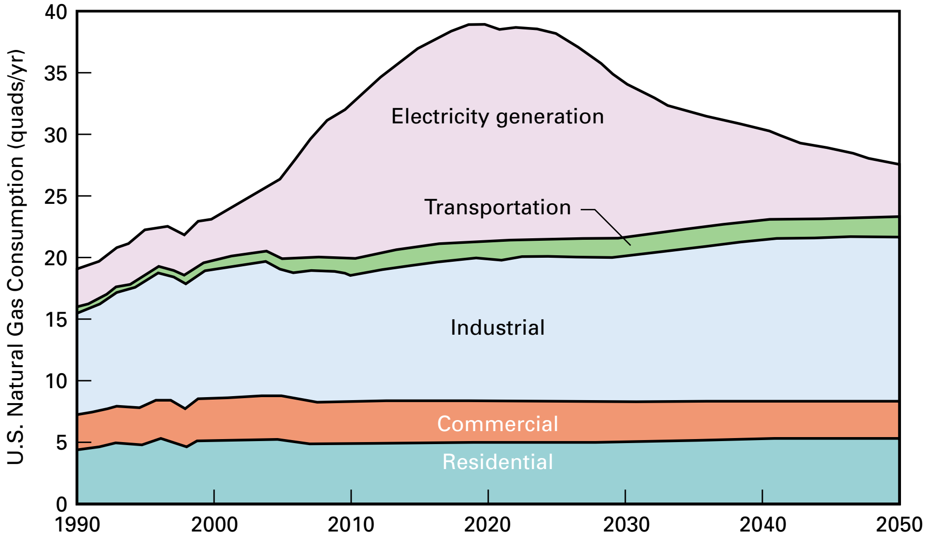
Apart from the difficulties of expanding natural gas use so quickly, increasing gas-fired generation to a 60% share by 2020 is likely to result in a constrained gas supply and rising prices, which could threaten the sustainability of a U.S. energy system relying so heavily on this fuel. It is uncertain how long domestic natural gas supplies will last. Depending on the assumptions made about economic growth, CO_2 reductions, and recoverable gas resources for the post-2020 period, the supply could become constrained as early as 2025 (if the current moratorium on offshore drilling is maintained) or after 2050 (given a more favorable set of assumptions).

With the economy relying heavily on natural gas and with its supply dwindling, its price would rise. (This would be in addition to carbon taxes, assumed in E-EPIC to be the mechanism for inducing reductions in CO_2 emissions.) Such a price hike would make natural gas less attractive even before the supply becomes physically limited. Indeed, the faster the growth of gas use due to CO_2 restrictions, the earlier and greater would be the price rise.

The rapid deployment of a new fleet of natural gas–fired power plants would place substantial stresses on the gas production and delivery infrastructure. To serve the 500 GW of added gas-fired capacity expected by 2020, U.S. exploration and drilling activity would have to be increased by roughly 70%, and over 2000 miles of new pipeline would have to be added to the existing network each year between 2005 and 2009.

Trouble after 2020

Beginning in about 2025, continuing technology advances—along with rising natural gas prices—could make other fuels increasingly attractive for meeting the growing demand for electricity. Environmental constraints will also increase the need for other fuel options. While natural gas as a fuel is only about 60% as carbon intensive as coal, its combustion does produce carbon emissions. Thus, even assuming natural gas is available, using it for generating electricity with the technologies available today cannot be considered a long-term, sustainable solution to the dilemma of reconciling CO_2 restrictions with U.S. energy needs. Rather, natural gas should be viewed as a valuable but limited energy resource that can provide a bridge to a future that will require sustainable, reliable, and secure U.S. energy supplies.



The Current Policy Direction would require rapid CO_2 reductions between 2005 and 2012. Most of these reductions are projected to come from the electricity generation sector, because—unlike the situation in the transportation sector, for example—a mature technology is already available for economically using a lower-carbon fuel, natural gas. As a result, electricity's share of U.S. natural gas consumption would grow from 15% today to around 45% by 2020.

Nonhydro renewable energy sources are certainly part of the longer-term solution. (Hydroelectric generation has limited growth potential, since the most viable sites have already been developed for power production.) Under the Current Policy Direction, nonhydro renewables, which today account for less than 2% of electricity generation, are projected to provide about 20% of generation by 2050. Achieving this level of penetration would require major technological and infrastructure advances. Photovoltaic solar power systems, which are still significantly more costly than other generation options, would require substantial efficiency improvement and cost reduction to play a major role in the power equation. The most promising of the renewable resource options appear to be wind farms and large biomass energy systems.

A new generation of nuclear power plants is also a possibility to help achieve CO_2 reductions and fill the energy gap left by dwindling and increasingly expensive natural gas supplies. In fact, the CO_2 restrictions imposed under the Current Policy Direction are projected to lead to the relicensing of existing nuclear plants—a departure from projections under a business-as-usual approach. However, given the technology assumptions used by EIA and carried over into the E-EPIC study, new nuclear plants are not projected to be economically competitive with other power generation options. These EIA assumptions were not evaluated or changed in E-EPIC, but lower-cost nuclear plants (designs for which have already received regulatory approvals) could very well play a significant role in meeting future carbon restrictions. Other technologies under development, such as fuel cells, may also have that potential, although early fuel cell technologies are expected to operate on natural gas.

E-EPIC indicates that coal, utilized by means of gasification and combined-cycle generation technologies, could be the fuel that fills the substantial remaining energy gap. The gasification process inherently limits SO_2 and NO_x emissions, and with the projected development of carbon capture and sequestration technologies (also applicable to other fossil fuels and to biomass), coal could once again become the lowest-cost fuel for electricity generation. There is considerable uncertainty about how soon economically viable technology and infrastructure could be developed for capturing fuel carbon—either before or after combustion—and transporting it to secure sequestration sites, such as deep aquifers, coal beds, or depleted oil and gas reservoirs. Nevertheless, available information indicates that this technological advance is possible over the study's time frame.

Perhaps a larger coal-related problem is that, under the Current Policy Direction, about two-thirds of the coal-fired plants will have been retired by 2020, with the supporting coal supply system also largely abandoned and unproductive. U.S. coal production is projected to drop in the next two decades, from about 1100 million tons per year today to just above 300 million tons per year by 2020. With coal consumption falling by more than 70%, mines would be closed, rail service in many mining areas could be discontinued, and local economies and labor forces would change considerably. Consequently, for renewed use after 2020, the national coal supply infrastructure would basically have to be rebuilt. Even if this could be accomplished, restoring a largely abandoned coal supply system to today's production levels would be costly.

Unproductive use of energy assets

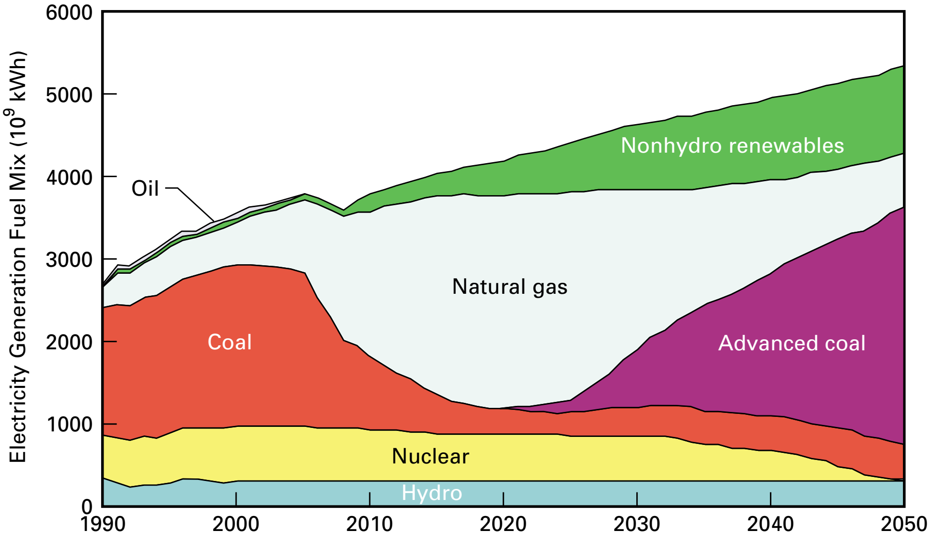
Changes in the U.S. energy system's fuel and technology requirements are inevitable. However, large and rapid changes can cause energy assets to be used less productively than is desirable or necessary. As described earlier, achieving significant CO_2 reductions under the Current Policy Direction would require the extensive deployment of available, economically viable technologies in the next 10–15 years. In the main, this means replacing coal-fired generation with natural gas generation. Such a rapid reduction in coal use would reduce the diversity and flexibility of the overall U.S. fuel mix and lead to faster consumption of finite natural gas reserves. As a result, the U.S. energy system could become more vulnerable to supply disruptions and fuel price volatility.

A failure to take into account the interplay of all the aspects of the future power equation is likely to lead to an inefficient solution. For example, proposed post-2000 caps on power plant SO_2 and NO_x emissions would require substantial investment in emissions control equipment for roughly 140 GW of coal-fired generating capacity. But this investment would be stranded if coal plants were retired or were used only intermittently as a result of subsequent CO_2 restrictions. It follows that power companies would be less likely to spend money on NO_x and SO_2 retrofits if they foresaw having to retire the plants soon anyway to comply with CO_2 emissions limits. As this example illustrates, neglecting to factor in CO_2 limits because of uncertainty about future energy policy could greatly worsen the problem of stranded emissions control investments.

Given the magnitude and timing of the CO_2 restrictions under the Current Policy Direction, stranding NO_x and SO_2 emissions controls could be avoided only by phasing out coal generation even earlier, ahead of the CO_2 emissions caps, or by delaying those caps. Not only would the former alternative reduce the ability of power companies to meet the expected growth in electricity demand, but it would also be likely to exacerbate the impacts on the natural gas infrastructure, decrease electricity service reliability, and accelerate a rise in electricity prices due to increasing gas prices.

Rapidly abandoning the productive use of existing coal-based energy assets might be acceptable if it made way for better-performing assets with long, productive lives. Unfortunately, this would not entirely be the case under the Current Policy Direction. Large amounts of quickly deployed *future* energy assets could themselves become uncompetitive and obsolete as a result of changing technology and market conditions.

Consider, for example, the new gas-fired generating capacity projected to be deployed over the next 20 years. Almost 200 GW would be needed under the Current Policy Direction—this in addition to about 300 GW already considered necessary just to serve growing electricity demand. Initially, the new gas-fired capacity would be very heavily utilized in order to meet CO_2 restrictions. However, its utilization is projected to drop off after 2020 as a result of rising gas prices and the availability of new, advanced technologies, including cost-effective processes for capturing and sequestering carbon from fossil fuels. It is possible that some of the natural gas–fired capacity could be modified to use coal-derived gas, but this development would require advance planning with respect to plant locations and designs. Other energy assets deployed under the Current Policy Direction could also be rendered unproductive, including portions of the natural gas supply infrastructure. It is normal for some new energy assets to become unproductive, but it is important that this fate not befall large amounts of assets deployed over a relatively short time to meet CO_2 reduction mandates.



The tremendous increase in demand for natural gas is expected to result in constrained supplies and higher gas prices by 2020. If such advances as carbon capture and integrated gasification–combined-cycle technologies become economical by then, as expected, coal could reemerge as the country's workhorse fuel for power generation.

In analyzing future energy markets, such as those that might develop under the Current Policy Direction, it is extremely difficult to anticipate and make "correct" competitive decisions. Thus, in actual practice, stringent CO_2 restrictions could result in even less efficient and less productive use of energy assets than projected here. Furthermore, courses of action that in general seem optimal may not be attractive to the energy companies that would have to make the investments; that is, companies may consider the potential profits to be insufficient to justify the risks raised by future uncertainties. For example, what companies will make the substantial investments required to keep advanced coal or biomass technology moving ahead when uncertainties about environmental requirements are added to already-large technology performance and market uncertainties?

Indeed, according to E-EPIC, the Current Policy Direction would not make effective use of technology advances and might even hinder them. A heavy focus on near-term objectives might come at the expense of strategies with longer-term payoffs and have potentially dramatic impacts on generation technology for years to come. A massive near-term deployment of natural gas–based generation technology could reduce other technologies' access to investment capital, power market opportunities, and operating experience, thereby slowing their development. The early imposition of stringent CO_2 emissions limits could have the paradoxical effect of hindering development of the improved generation technologies needed to reconcile energy and environmental objectives over the long term.

These other technologies will require time for R&D, practical commercial application, and infrastructure development. It is possible to promote faster technology advances as well as to emphasize strategies that balance the fuel, technical, and environmental vulnerabilities of various technologies. Such coordinated strategies would reduce the risk of investing in the "wrong" technologies and facilities or deploying too much of one particular technology. However, the pace of CO_2 reductions under the Current Policy Direction could be too rapid to permit such efforts to come to fruition. For example, it may be difficult for key nonhydro renewable generation technologies and their supporting infrastructures to expand as fast as projected; under the Current Policy Direction, a biomass supply system producing some 200 million tons per year would have to be developed by 2020, starting from essentially nothing today, and wind farms would have to cover an area larger than Rhode Island.


Under the CO_2 emissions restrictions of the Current Policy Direction, about two-thirds of U.S. coal-fired power plants would be retired by 2020, leading to the reduction or abandonment of much of the existing coal mining and transportation infrastructure. The nation's coal supply system would have to be reestablished at great cost if advanced clean coal options take off in the second quarter of the century.

Tweaking the timing and technology

Additional analyses were performed for an alternative policy and for some alternative assumptions about post-2020 technology costs and performance. As anticipated, these resulted in somewhat different projected effects on the U.S. electricity sector. The alternative policy scenario, called the Carbon Glide Path to 2030, differs from the Current Policy Direction by omitting additional SO_2 restrictions beyond phase 2 of the Acid Rain Program and by modifying the schedule of CO_2 restrictions. In this scenario, CO_2 reductions still begin in 2005, but they tighten more gradually—out to 2030—with a lower final CO_2 emissions cap so that the cumulative carbon emissions from 2000 through 2050 are the same. In other words, the *rate* of tightening carbon restrictions is slowed while both the extent of the ultimate reductions and the timing of the initial reductions are maintained.

The analysis found that the Carbon Glide Path scenario would slightly lessen the adverse effects of the Current Policy Direction by reducing short-term impacts on the national economy, slowing the transition from coal generation to natural gas, and reducing—to a limited degree—the amount of gas-based generation technology that would be deployed over the next two decades. However, the conclusion was that, while helpful, this particular policy adjustment would be insufficient to avoid many of the undesirable consequences of the Current Policy Direction.

Other analyses examined alternative assumptions about the cost and performance of technologies after 2020. Although preliminary, these analyses give an indication of how the alternative assumptions could affect projections of the mix of fuels used for electricity generation after 2020. For example, if capital costs for a new generation of nuclear power plants could be reduced substantially from those assumed by EIA (say, by 25% or 33%, which might be achieved by utilizing standardized plant designs), the result could be a greatly increased use of nuclear power after 2020; this, in turn, could reduce the amount of coal, gas, and biomass used for electricity generation.

Another example involves the costs of capturing and sequestering carbon emissions from fossil-fired generating plants. If these costs were significantly higher than assumed under the Current Policy Direction, then the future use of coal for electricity generation would be reduced; it would be replaced either by higher natural gas use or by nuclear power, depending on assumptions regarding their respective costs. Further analyses will provide more insights into the effects of crucial assumptions about technology advances, fuel prices, and other factors.

A need for coordination

E-EPIC provides no easy answers. Clearly the crux of the problem is that—given the assumptions and methodology used in this analysis—the Current Policy Direction would require large CO_2 emissions reductions before technologies suited to cost-effectively sustaining those reductions could realistically be developed and deployed. The result would be a forced energy supply system response that would be unnecessarily disruptive and perhaps even unfeasible. Slowing the rate at which CO_2 reductions are made while preserving the early start and long-term commitment to the reductions might alleviate the problem to a certain extent; however, delaying CO_2 reductions is not the sole solution.

To truly address uncertain future needs, there must be greater coordination of environmental policy with energy policy, especially with a realistic, accelerated program of energy technology development. Policies for reducing emissions should provide clear incentives and market signals for changing the U.S. energy system without overwhelming the system or irreparably damaging its infrastructure. The development and commercialization of key energy technologies with long-term promise must be promoted by creating R&D programs and incentives and by refining environmental policies so that they permit and encourage desirable technology advances.

WARREN GRETZ/NATIONAL RENEWABLE ENERGY LABORATORY

Renewable energy resources are generally expected to play an increasing role in power production; however, it may be difficult for renewable technologies and their infrastructures to be developed and deployed as fast as necessary under the Current Policy Direction, which would entail a 10-fold capacity increase by 2020. With the continued high cost of solar power systems, the most promising of the renewable options appear to be wind farms and large biomass energy systems based on fast-growing trees or switchgrass.

The most prudent plans will emphasize the practical realization of a variety of energy technologies with offsetting strengths and vulnerabilities. EPRI's Electricity Technology Roadmap, a multistakeholder plan for energy technology development, identifies not only technology advances that could be feasible and desirable but also the resources necessary to achieve them.

Although E-EPIC indicates that the Current Policy Direction is far from an optimal approach to reducing CO_2 and other emissions associated with energy use in the United States, this does not mean that substantial long-term CO_2 reductions are unfeasible or undesirable. In fact, the energy system that is projected to emerge by 2050 under the Current Policy Direction would be more efficient, flexible, and sustainable than the system that would emerge under a business-as-usual approach, and it would make greater use of renewable energy fuels and technologies.

What is needed, however, is a less risky and less costly path to an efficient, low-carbon-emitting energy system—a path that also takes into account interactions with schedules for reducing other emissions. With that kind of policy approach, CO_2 reductions could be achieved while realistic progress is made toward developing and deploying sustainable energy technologies. Better coordination between our national energy and environmental policies would allow us to avoid disruptions, inefficiencies, and risks to the U.S. energy system and economy during a transition that will certainly take decades rather than years to achieve. ■

Effects on the U.S. Economy

As limits on carbon emissions go into effect under the Current Policy Direction, energy prices are projected to rise and the growth of the U.S. economy to slow. According to the E-EPIC study, these policies would increase the price of electricity 50% by 2020, and average annual household energy expenditures (excluding those for transportation) would increase by over 20% (about $300), even though energy use would decline by 15%. Some regions, such as the Midwest and the Southeast, would experience even greater price increases. The price increases in the energy system would produce a ripple effect throughout the national economy, boosting inflation. Between 2008 and 2020, the increase in consumer prices attributable to the Current Policy Direction would average over 2% per year.

E-EPIC's projections of economic effects through 2020 are generally consistent with EIA's analysis of the potential effects of the Kyoto Protocol. In the longer term—beyond about 2030, after advanced technologies have been deployed and the economy has absorbed the large initial investment costs and market shifts—economic growth can be enhanced by the use of the new, more efficient energy technologies. However, the question remains as to what superior paths to this long-term future might be followed so as to achieve environmental objectives and a more efficient energy system while avoiding unnecessary short-term economic effects and inefficient investments in the energy infrastructure. □

Further reading

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In the Field

Demonstration and application of EPRI science and technology

AEP Tests Microturbine Performance

American Electric Power has conducted the first detailed electrical tests of how a microturbine generator (MTG) interacts with the power grid and other electrical devices in a utility environment. These and future tests scheduled at AEP are part of an EPRI initiative to assess the viability of microturbines for field application as distributed generators and to identify critical technical issues for the emerging technology.

COURTESY AMERICAN ELECTRIC POWER CO.

“We’re developing firsthand knowledge of real-world MTG electrical performance—knowledge not yet available elsewhere,” says Dave Nichols, who manages AEP’s John E. Dolan Laboratory near Columbus, Ohio, where the MTG test program is being conducted. Adds Doug Herman, EPRI manager for distributed resource applications, “Utilities, energy service providers, and customers planning to use microturbines need to understand how they work before making a purchase or investment. The test program seeks to determine the readiness of MTGs for utility service and to define potential benefits to utilities and customers from applying MTGs in the distribution system.”

At the Dolan laboratory, MTG units are installed on a large outdoor test pad, which is served by both 500-kVA and 30-kVA transformers and by natural gas at a pressure of 5 psig (34.5 kPa). The unit for the first series of tests, conducted in late 1999, was Capstone Turbine’s 30-kW model 330. Both normal and emergency utility conditions were simulated.

Steady-state tests of the grid-connected Capstone MTG evaluated overall system efficiency, power quality, radio-frequency interference, audible noise, and emissions at four power settings (25%, 50%, 75%, and 100%). Gas flow and ambient weather conditions were also recorded. To simulate a strong electrical source, AEP personnel connected the generator to the 500-kVA transformer; to simulate a weak source, they connected it to the 30-kVA transformer. Additional tests assessed electromagnetic compatibility and examined how MTG operation was affected by distribution system voltage imbalance, electrical stress, and nearby motor loading. Results from all the tests are presented in EPRI report TR-114270.

“The application of microturbine generators is still evolving and ultimately depends on the technology’s implementation by utilities and others,” says Herman. “Tests such as those at AEP’s Dolan lab are important because they help identify, before wide commercial introduction, how microturbines will interact with utility and end-user grids.”

This year, AEP will conduct characterization and performance tests on MTGs from various manufacturers, in both grid-connected and stand-alone modes. When applicable, the results will be compared with the manufacturers’ preliminary specifications and with other criteria cited in IEEE, ANSI (American National Standards Institute), and IEC (International Electrotechnical Commission) standards.

EPRI is also managing a parallel program to evaluate the performance, durability, reliability, and maintainability of MTG systems after they are placed in field operation. “Microturbine performance is steadily improving,” says Herman, “but more work is needed to achieve the desired goals. A critical question, to be addressed by the field test program, is the long-term durability of the equipment.”

■ *For more information, contact Doug Herman, dherman@epri.com, 650-855-1057.*

Intelligent Sootblowing System Documented

Residues from coal combustion in power plant boilers accumulate on the surface of boiler tube banks, where they impede heat transfer and reduce efficiency. Over time, large deposits can detach from the banks and fall to the bottom of the furnace, damaging tubes and other equipment. These deposits are removed by sootblowing, but overuse of this technique can itself cause problems, including tube erosion. Optimizing a sootblowing schedule is thus a key operational concern.

EPRI has documented the experience of the British utility PowerGen in developing and implementing an “intelligent” system to advise plant operators about when and in which boiler areas to perform sootblowing. A fuzzy logic approach was used to capture the experience of expert operators and encode it in the system.

Such a system offers several advantages over other methods proposed by vendors. In contrast to model-based techniques, it uses the knowledge of skilled operators explicitly. It is also more robust and has less-rigorous data requirements than model-based techniques. And unlike systems that rely on direct heat flux measurements, a system based on fuzzy logic does not require additional equipment.

PowerGen's intelligent system was designed for use at the Kingsnorth station. In trials there, the system gave sound, clear sootblowing advice. Short-term efficiency gains were negligible, however, confirming results from other studies. "This means that in making an economic case for such a system, it is necessary to quantify the value of benefits in other areas—namely, operational support and avoided maintenance," says Ramesh Shankar, an EPRI project manager for instrumentation and control. The results of the Kingsnorth case study are presented in EPRI report TR-114420.

■ *For more information, contact Ramesh Shankar, rshankar@epri.com, 704-547-6127.*

COURTESY THE MODO GROUP

PQPager Answers Call in Sweden

The MoDo Group, a major Swedish paper producer, is one of the first industrial firms outside North America to apply EPRI's PQPager on a continuing basis to monitor power quality problems. Implementation of this easy-to-use voltage sag monitor is a key element in the power quality service offered by MoDo's energy supplier, Vattenfall.

For several years, MoDo—which produces print paper, fine paper, and high-quality paperboard—repeatedly experienced lightning-related production disturbances at seven of its facilities. The company estimated the annual cost of these problems at 1 million Swedish kronor ($125,000) or more at each plant. It was difficult to develop mitigation measures because of inadequate information about the nature of the disturbances. MoDo asked Vattenfall, one of Sweden's largest utilities, to investigate the situation and, if possible, improve power quality.

Vattenfall installed PQPagers in the seven MoDo paper and cardboard production facilities in 1998. Featuring a low-cost monitor mounted near a customer meter, the PQPager can communicate with other units or a central computer. It can automatically telephone a utility account representative or a customer engineer to present, in a synthesized voice, the details of power quality problems as they occur.

PQPager monitoring data for a facility are used with a customer log of operating problems to establish a power disturbance immunity curve showing the relationship between power quality and the behavior of the facility's process equipment. Such curves are used in identifying the need for power quality audits and in selecting the most cost-effective solutions to problems.

In the summer of 1998, considered normal in terms of lightning activity, the PQPagers at the MoDo facilities registered a total of over 50 power quality disturbances, mostly brief voltage sags and outages. According to analyses of the disturbance immunity curves generated for the sites, some 80% of the problems could have been avoided through the use of more-modern equipment.

Vattenfall will continue to monitor the MoDo facilities to better understand their sensitivities to voltage sags and to evaluate cost-effective solutions. MoDo and Vattenfall are working together to avoid production downtime caused by modest voltage disturbances.

"The PQPager is a valuable tool that lets us tune our own process equipment and determine the quality of the electricity the energy provider is delivering to us," says Erik Olsson of the MoDo Group. Adds Andrejs Ritums, manager of Vattenfall's Power Quality Center, "The PQPager is an economical and highly flexible tool for quickly providing power quality information to our customers as well as to various other areas of our own organization."

■ *For more information, contact Marsha Grossman, mgrossma@epri.com, 650-855-2899.*

Technical Reports & Software

To place an order, call EPRI Customer Service at 800-313-3774 or 650-855-2121, and press 1 for software or 2 for technical reports. Target funders can download an Acrobat PDF file of a technical report by searching for the report number on EPRI's Web site (www.epri.com).

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Flywheels for Electric Utility Energy Storage
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EPRI Project Manager: S. Eckroad

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TR-110719
Target: Substation Assets Utilization
EPRI Project Manager: S. Eckroad

Multimode Transportable Battery Energy Storage System for Salt River Project, Vol. 2: Analysis of First-Year Performance Testing
TR-110859-V2
Target: Distribution Systems
EPRI Project Manager: S. Eckroad

FACTS With Energy Storage: Conceptual Design Study
TR-111093
Targets: Substation Assets Utilization; Distribution Systems
EPRI Project Manager: S. Eckroad

TimeLine User Manual: Environment for Specification and Analysis of Sequential Control Systems
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EPRI Project Managers: A. Massoud

Remotely Controlled Manhole Cover Removal System
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Target: Underground Distribution Infrastructure
EPRI Project Manager: R. Bernstein

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EPRI Project Manager: W. Zenger

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Airborne Inventory and Inspection of Transmission Lines: Unmanned Airborne Vehicles
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EPRI Project Manager: A. Phillips

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Dissolved-Gas Analysis for Fluid-Filled Terminations of Extruded Transmission Cables
TR-114197
Target: Underground Transmission
EPRI Project Manager: W. Zenger

Straw-Man Device Object Models for Distributed Resources in Utility Communications Architecture (UCA™)
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EPRI Project Manager: F. Goodman

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Underground Cable Installation and System Cost Reduction, Phase 2: Design Tradeoffs
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Target: Underground Transmission
EPRI Project Manager: T. Rodenbaugh

💾 PSAPAC (Power System Analysis Package): DYNRED, ETMSP, IPFLOW, SSSP, VSTAB
Version 5.1 (Windows 95, 98, NT); AP-114704
Target: Grid Planning and Development
EPRI Project Manager: P. Hirsch

💾 PSAPAC: LOADSYN (Load Synthesis Program)
Version 1.0 (Windows 95, 98, NT); AP-114818-P4
Target: Grid Planning and Development
EPRI Project Manager: P. Hirsch

💾 RCM Workstation for Power Delivery
Version 1.1 (Windows 95, 98); AP-108076-R1
Targets: Distribution Systems; Overhead Transmission; Underground Transmission; Substation O&M
EPRI Project Manager: P. Vujovic

💾 Topology Processor
Version 2.0 (Windows NT 4.0); AP-114699
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Estimated Aqueous Release Concentrations of Multi-Ring Aromatic Hydrocarbons From MGP Soils
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EPRI Project Manager: A. Quinn

Proceedings: Fourth International Conference on Managing Hazardous Air Pollutants
TR-111024
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EPRI Project Managers: P. Chu, L. Levin

Remediation of Gas Holders at MGP Sites
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EPRI Project Manager: A. Jain

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TR-112746
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EPRI Project Manager: J. Goodrich-Mahoney

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EPRI Project Manager: J. Goodrich-Mahoney

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EPRI Project Manager: J. Goodrich-Mahoney

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EPRI Project Manager: K. Ladwig

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TR-114220
Target: Facilities Water Management
EPRI Project Manager: J. Goodrich-Mahoney

Traffic Density as a Risk Factor for Childhood Cancer in Denver and Los Angeles
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Target: Residential and Community Health Assessment
EPRI Project Manager: K. Ebi

💾 **MagShield**
Version 1.0 (Windows 95, 98, NT); AP-114730
Target: Electromagnetic Compatibility
EPRI Project Manager: F. Young

Fossil and Renewable Generation

Streamlined Reliability-Centered Maintenance (SRCM) Implementation Guidelines
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EPRI Project Manager: R. Pflasterer

European Union Wind Energy Forecasting Model Development and Testing
TR-112146
Target: Renewable Technology Options and Green Power Marketing
EPRI Project Manager: C. McGowin

Hydro Life Extension Modernization Guide, Vol. 1: Overall Process
TR-112350-V1
Targets: Hydropower Operations and Asset Management; Relicensing Forum; Plant Maintenance and Life Management
EPRI Project Manager: D. Gray

Project Development Experience at the Iowa and Nebraska Distributed Wind Generation Projects
TR-112835
Target: Renewable Technology Options and Green Power Marketing
EPRI Project Manager: C. McGowin

Guidelines for Upgrading Electrostatic Precipitator Performance: Upgrade Options
TR-113582-V2
Target: Primary Particulate Control
EPRI Project Manager: R. Altman

Technology Assessment of Residential Power Systems for Distributed Generation Markets
TR-113897
Target: Fuel Cell Distributed Power Systems
EPRI Project Manager: B. Freeman

Central and South West Wind Power Project Third-Year (1998–1999) Operating Experience
TR-113916
Target: Renewable Technology Options and Green Power Marketing
EPRI Project Manager: C. McGowin

Green Mountain Power Wind Power Project Second-Year (1998–1999) Operating Experience
TR-113917
Target: Renewable Technology Options and Green Power Marketing
EPRI Project Manager: C. McGowin

Kotzebue Electric Association Wind Power Project Development
TR-113918
Target: Renewable Technology Options and Green Power Marketing
EPRI Project Manager: C. McGowin

Big Spring Wind Power Project Development
TR-113919
Target: Renewable Technology Options and Green Power Marketing
EPRI Project Manager: C. McGowin

Thermal Performance of the ABB GT24 Combustion Turbine: Peaking Service Experience
TR-113978
Target: New Combustion Turbine/Combined-Cycle Design, Repowering, and Risk Mitigation
EPRI Project Manager: J. Scheibel

Combustion Turbine Spray Cooler Guide
TR-113983
Target: Combustion Turbine and Combined-Cycle O&M
EPRI Project Manager: J. Scheibel

Combustion Turbine Axial Compressor Monitor
TR-113985
Target: Combustion Turbine and Combined-Cycle O&M
EPRI Project Manager: J. Scheibel

Performance of Siemens V84.3A Combustion Turbine: Peaking Service Experience
TR-113986
Target: New Combustion Turbine/Combined-Cycle Design, Repowering, and Risk Mitigation
EPRI Project Manager: J. Scheibel

Technology Risk Assessment in Combustion Turbine–Based Power Plants
TR-113988
Target: New Combustion Turbine/Combined-Cycle Design, Repowering, and Risk Mitigation
EPRI Project Manager: J. Scheibel

Boiler Reliability Optimization: Interim Guideline
TR-113997
Targets: Plant Maintenance Optimization; Predictive Maintenance Program Development and Diagnostic Tools
EPRI Project Manager: P. Abbott

Guidelines for Assessing the Feasibility of District Energy Projects
TR-114071
Target: Integrated Energy Services Using Local Energy Networks
EPRI Project Manager: D. Gray

Engineering Economic Evaluation of Clean Coal Technologies, 1999
TR-114080
Target: Coal Power Systems Development
EPRI Project Manager: N. Holt

The Kellogg Brown & Root Transport Reactor: PSDF Test Results and Economic Evaluation
TR-114083
Target: Coal Power Systems Development
EPRI Project Manager: J. Wheeldon

Operating Experience and Risk Assessment of Clean Coal Technologies, 1999
TR-114084
Target: Coal Power Systems Development
EPRI Project Manager: N. Holt

Interim Guidelines for Reducing Turbine Generator Maintenance Overhauls and Inspections, Vol. 1: General Practices
TR-114128-V1
Target: Steam Turbines, Generators, and Balance of Plant
EPRI Project Manager: T. McCloskey

Repowering the 250-MW Supercritical Power Plant at Lenenergo, Russia
TR-114190
Target: Repowering Designs, Regional Assessments, and Analysis Tools
EPRI Project Manager: D. Gray

Operations and Maintenance Workstation, Version 2.0: Reference Manual
AP-114214
Targets: Plant Maintenance Optimization; O&M Workstation User Group
EPRI Project Manager: R. Pflasterer

Nondestructive Evaluation of Combustion Turbine Coatings
TR-114221
Target: Combustion Turbine and Combined-Cycle O&M
EPRI Project Manager: V. Viswanathan

Model-Based Condition Monitoring From Rotating Machinery Vibration
TR-114223
Target: Steam Turbines, Generators, and Balance of Plant
EPRI Project Manager: D. Gray

Advanced Condition Monitoring of Hydrogenerators: Knowledge Base
TR-114245
Targets: Steam Turbines, Generators, and Balance of Plant; Plant Maintenance and Life Management
EPRI Project Manager: J. Stein

Operator Certification Standards for Fossil Fuel–Fired Plants: Survey of State and Regional Requirements
TR-114259
Target: Training and Simulators for Human Performance Enhancement
EPRI Project Manager: R. Pennington

Remote Equipment Diagnostics: Infrastructure Description
TR-114283
Targets: Plant Maintenance Optimization; Predictive Maintenance Program Development and Diagnostic Tools
EPRI Project Manager: R. Pflasterer

Blade Management System for Advanced F Class Gas Turbines
TR-114312
Targets: Combustion Turbine and Combined-Cycle O&M; 7/9 FA Life Management System
EPRI Project Manager: V. Viswanathan

Work Culture and Process Improvement: Predictive Maintenance—Case Study
TR-114324
Targets: Plant Maintenance Optimization; Work Process Improvement Guidelines and Techniques
EPRI Project Manager: R. Pflasterer

Application Guidelines for Advanced Control in Fossil Plants
TR-114339
Target: I&C and Automation for Improved Plant Operations
EPRI Project Manager: R. Torok

💾 **CRFLOOD: Uplift Pressure Distribution and Drain Effectiveness**
Version 1.0 (PC-DOS); AP-101596
Target: Hydropower Operations and Asset Management
EPRI Project Manager: D. Morris

Nuclear Generation

DAW and Mixed LLW Processing and Volume Reduction Technologies
TR-107331
Target: Nuclear Power
EPRI Project Manager: C. Hornibrook

Development of Energy Production Systems From Heat Produced in Deuterated Metals, Vol. 2
TR-107843-V2
Target: Nuclear Power
EPRI Project Managers: A. Machiels, T. Passel

Fuel Cladding Integrity at High Burnup: Part 1 (Hydraulic Burst Tests, Tensile Tests on Large Samples); Part 2 (Uniaxial Tensile Tests, Slotted Arc Tests on Small Samples)
TR-108753-P1; TR-108753-P2
Target: Nuclear Power
EPRI Project Manager: S. Yagnik

Materials Handbook for Nuclear Plant Pressure Boundary Applications
AD-109668-R1
Target: Nuclear Power
EPRI Project Manager: L. Nelson

AOA Chemistry Diagnostic: Fuel Deposit Source Term Reduction by Elevated pH (Interim Report)
TR-110073
Target: Nuclear Power
EPRI Project Manager: P. Frattini

Surface Chemistry Interventions to Control Boiler Tube Fouling
TR-110083
Target: Nuclear Power
EPRI Project Manager: P. Frattini

Development of an LP Rotor Rim-Attachment Cracking Life Assessment Code (LPRimLife)
TR-110407
Target: Nuclear Power
EPRI Project Managers: D. Gandy, V. Viswanathan

Colloid Transport and Deposition in Water-Saturated and Unsaturated Sand and Yucca Mountain Tuff: Effect of Ionic Strength and Moisture Saturation
TR-110546
Target: Nuclear Power
EPRI Project Manager: J. Kessler

Understanding of Thermal Diffusivity Recovery With Thermal Annealing
TR-111068
Target: Nuclear Power
EPRI Project Manager: S. Yagnik

In Situ Investigation of the Surface Films Formed on Iron-Nickel-Chromium Alloys in High-Temperature Water and Their Relevance to Stress Corrosion Cracking
TR-112301
Target: Nuclear Power
EPRI Project Manager: L. Nelson

Weld Overlay of Waterwall Tubing, Alternative Materials, and Distortion
TR-112643
Target: Nuclear Power
EPRI Project Managers: K. Coleman, D. Gandy

Assessment of Chromium Coating Technology
TR-112982
Target: Nuclear Power
EPRI Project Manager: H. Ocken

Performance of NOREM™ Hardfacing Alloys
TR-112993
Target: Nuclear Power
EPRI Project Manager: H. Ocken

Guidelines for Industry Response to Personnel Contaminants
TR-113039
Target: Nuclear Power
EPRI Project Manager: C. Hornibrook

EPRI MOV Performance Prediction Program: An Improved and Validated Gate Valve Unwedging Methodology
TR-113564
Target: Nuclear Power
EPRI Project Manager: J. Hosler

Accelerated Testing for High-Temperature Materials Performance and Remaining Life Assessment
TR-114045
Target: Nuclear Power
EPRI Project Manager: V. Viswanathan

Eddy-Current Data Quality Specification for Inspection of Steam Generator Tubes, Vol. 1: Bobbin Coil Probe
TR-114206-V1
Target: Nuclear Power
EPRI Project Manager: J. Benson

BWR Vessel and Internals Project: BWR Core Shroud Inspection and Flaw Evaluation Guidelines
TR-114232
Target: Nuclear Power
EPRI Project Manager: R. Carter

BWR Vessel and Internals Project: Crack Growth Under Simulated BWR Conditions—MIT Sensor Program
TR-114277
Target: Nuclear Power
EPRI Project Manager: R. Pathania

A Robotic System for the Maintenance of Boiler Hopper Systems in Power Plants
TR-114419
Target: Nuclear Power
EPRI Project Manager: R. Shankar

💾 Waste Logic™: FASTTRACK 2000
Version 1.0 (Windows 95, 98, NT); AP-114520
Target: Nuclear Power
EPRI Project Manager: S. Bushart

Retail and Power Markets

Gas Hot Top Under Wall-Mounted Canopy Hood: Standard Test Method for the Performance of Commercial Kitchen Ventilation
TR-106493-V17
Target: Foodservice Facilities Solutions
EPRI Project Manager: J. Kuegle

Commercial Kitchen Ventilation Performance Report: Electric Hot Top Under Wall-Mounted Canopy Hood
TR-106493-V18
Target: Foodservice Facilities Solutions
EPRI Project Manager: J. Kuegle

Project Res-IDENT: Qualitative Assessment of Home Networking Appliances
TR-109197
Target: Opportunities in Networked Home Services
EPRI Project Manager: C. McAllister

Community Networks: Local Content-Rich Websites—A New Role for Energy Companies
TR-111060
Target: Opportunities in Networked Home Services
EPRI Project Manager: C. McAllister

Fast-Charging Demonstration at Honda of America's East Liberty Plant
TR-113892
Target: Industrial and Recreational Transportation
EPRI Project Manager: G. Krein

Safety Criteria for Isolated Direct-Current Systems in Electric Vehicles: Traction Motor and Control Circuitry Under Charging and Driving Conditions
TR-114089
Targets: Personal and Automotive Fleet Transportation/Infrastructure; Industrial and Recreational Transportation
EPRI Project Manager: G. Krein

Power Quality Contracting Guidelines: A Roadmap to Guaranteed Service
TR-114142
Target: Power Quality Contracting Guidelines
EPRI Project Manager: W. Moncrief

Emissions Modeling for Electric Vehicles: Progress Report
TR-114173
Target: Personal and Automotive Fleet Transportation/Infrastructure
EPRI Project Manager: L. Sandell

Uncertainty Representation: Estimating Process Parameters for Forward Price Forecasting
TR-114201
Target: Asset and Risk Management
EPRI Project Manager: V. Niemeyer

Design and Evaluation of an Advanced Charging Current Interrupting Device (CCID) Prototype
TR-114227
Targets: Personal and Automotive Fleet Transportation/Infrastructure; Energy Storage Systems
EPRI Project Manager: G. Krein

Roadmap for Power Quality Mitigation Technology Demonstration Projects at Commercial Customer Sites
TR-114240
Target: Power Quality for Satisfied Residential and Commercial Customers
EPRI Project Manager: B. Banerjee

Custom-ER Settlement Agent (CSA): Technical Description
TR-114253
Target: Advanced Billing and Customer Operations Systems
EPRI Project Manager: D. Cain

Evaluation of Embedded Solutions for Decreasing Sensitivity of End-Use Equipment to Power Quality Variations
TR-114260
Target: Power Quality for Improved Industrial Operations
EPRI Project Manager: B. Banerjee

Geothermal HVAC System Performance in a Quick-Service Restaurant: Field Experience From McDonald's Demonstration
TR-114261
Target: Commercial Heat Pump/Air Conditioner Technology
EPRI Project Manager: M. Khattar

HVAC System Design Strategies to Address Indoor Air Quality Standards
TR-114262
Target: Commercial Heat Pump/Air Conditioner Technology
EPRI Project Manager: M. Khattar

A Reliability Study of Electric Vehicle Supply Equipment
TR-114264
Target: Personal and Automotive Fleet Transportation/Infrastructure
EPRI Project Manager: L. Sandell

Power Quality Mitigation Technology for Industrial Processes
TR-114265
Target: Power Quality for Improved Industrial Operations
EPRI Project Manager: B. Banerjee

Testing of TEC-Based TMS for Patrol EV and Bus Fleet Vehicles
TR-114266
Target: Energy Storage Systems
EPRI Project Manager: R. Swaroop

1999 DaimlerChrysler EPIC NiMH Charging Systems Study
TR-114267-V1
Target: Energy Storage Systems
EPRI Project Manager: R. Swaroop

1999 DaimlerChrysler EPIC Performance Characterization: SAFT NiMH Battery—Conductive Charging
TR-114267-V2
Target: Energy Storage Systems
EPRI Project Manager: R. Swaroop

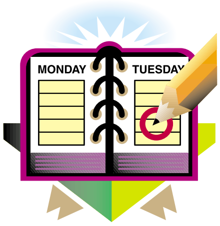
1999 Toyota RAV 4 EV NiMH Charging Systems Study
TR-114268-V1
Target: Energy Storage Systems
EPRI Project Manager: R. Swaroop

1999 Toyota RAV 4 EV Performance Characterization: Panasonic NiMH Battery—Conductive Charging
TR-114268-V2
Target: Energy Storage Systems
EPRI Project Manager: R. Swaroop

Managing Transmission Risk
TR-114276
Target: Asset and Risk Management
EPRI Project Manager: V. Niemeyer

Emerging Power Electronics Technologies: Application of Power Electronics in Power Quality
TR-114280
Target: Power Electronics
EPRI Project Manager: B. Banerjee

Energy Venture Investing Guidebook: Managing the Investment Process
TR-114282
Target: Producing Successful Retail Products and Services
EPRI Project Manager: B. Kalweit



EPRI Events

July

19
Business Venture Forum (formerly Technology Vendor Workshop)
Boston, Massachusetts
Contact: Laura Goldie, 650-855-2560

19–21
International Low-Level-Waste Conference
San Antonio, Texas
Contact: Cindy Layman, 650-855-8763

19–21
NDE Technical Skills Training: Level 3 Specific
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

24–25
Service Water System Reliability Improvement Seminar
Branson, Missouri
Contact: Brent Lancaster, 704-547-6017

24–28
Simulator and Training Center Interest Group
Castine, Maine
Contact: Richard Pennington, 704-547-6105

24–28
Visual Examination: Level 3
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

26–28
6th International Energy Pricing Conference
Washington, D.C.
Contact: Barbara McCarthy, 650-855-2127

26–28
Terry Turbine Users Group
Williamsburg, Virginia
Contact: Linda Parrish, 704-547-6061

27–28
Cooling Water Application Users Group
Branson, Missouri
Contact: Doug Munson, 650-855-2573

31–August 2
International Conference on Fatigue of Reactor Components
Napa, California
Contact: Susan Otto-Rodgers, 704-547-6072

31–August 4
Steam Plant Operations for Plant Personnel
Maritime, Maine
Contact: Richard Pennington, 704-547-6105

August

1–2
Lightning Protection Design Workstation (LPDW) 5.0
Dallas, Texas
Contact: Lynn Stone, 972-556-6529

7–8
5th National Green Power Marketing Conference
Denver, Colorado
Contact: Cindy Layman, 650-855-8763

7–8
Nuclear Plant Performance Improvement Seminar
Chicago, Illinois
Contact: Brent Lancaster, 704-547-6017

7–10
Weld Overlay Examination
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

8
EPRI Research Supporting Hydro Licensing Activities
Charlotte, North Carolina
Contact: Doug Dixon, 804-642-1025, or
Mike Bahleda, 704-547-6076

8–11
Generator Monitoring and Diagnostics
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

8–11
Pressure Relief Valve Application, Maintenance, and Testing
Orlando, Florida
Contact: Sherryl Stogner, 704-547-6174

14–16
Air-Operated Control Valve Application, Maintenance, and Diagnostics
Orlando, Florida
Contact: Sherryl Stogner, 704-547-6174

14–18
NDE Instructor Training
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

15–16
Power Quality Business Opportunities
Dallas, Texas
Contact: Lynn Stone, 972-556-6529

17–18
Manhole Event Workshop
Lenox, Massachusetts
Contact: Andrea Duerr, 650-855-2719

20–24
EPRI-AFS Symposium on Catadromous Eels
St. Louis, Missouri
Contact: Doug Dixon, 804-642-1025

20–24
EPRI-AFS Symposium on Sturgeon
St. Louis, Missouri
Contact: Doug Dixon, 804-642-1025

21–24
Cooling Tower Seminar and Conference
Jackson Hole, Wyoming
Contact: Brent Lancaster, 704-547-6017

21–25
Infrared Thermography: Level 2
Upper Marlboro, Maryland
Contact: Sherryl Stogner, 704-547-6174

22–24
On-Line Generator Monitoring
Columbus, Ohio
Contact: Jan Stein, 650-855-2390

23–24
Flow Measurement
Kingston, Tennessee
Contact: Sherryl Stogner, 704-547-6174

28–31
NMAC Westinghouse Circuit Breaker Users Group
Denver, Colorado
Contact: Linda Parrish, 704-547-6061

29–30
Transmission Line Lightning, Grounding, and Surge Arresters
Lenox, Massachusetts
Contact: Kyle King, 413-448-2459

September

9–13
7th International Symposium on Environmental Concerns in Rights-of-Way Management
Calgary, Canada
Contact: John Goodrich-Mahoney,
202-293-7516

11–12
ORSERG (Operational Reactor Safety Engineering and Review Groups) Workshop
Charlotte, North Carolina
Contact: Cindy Layman, 650-855-8763

11–15
NDE of High-Energy Piping
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

12
Power Quality Basics
Charlotte, North Carolina
Contact: Lynn Stone, 972-556-6529

12–14
Pulverizer Operations and Maintenance
Kingston, Tennessee
Contact: Sherryl Stogner, 704-547-6174

12–14
Root-Cause Analysis
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

13–15
Value and Risk Training
Washington, D.C.
Contact: Peggy Prater, 650-855-2951

14–15
UCA Substation Communication Initiative: 5th Interoperability Demonstration
Grand Rapids, Michigan
Contact: Bill Blair, 650-855-2173

18–22
Steam Plant Operations for Plant Personnel
Charlotte, North Carolina
Contact: Richard Pennington, 704-547-6105

18–29
Ultrasonic Examination: Level 1
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

25–26
4th Annual Power Switching Safety and Reliability Conference
Portland, Oregon
Contact: Debbie Marcin, 410-379-8020

25–29
Combined-Cycle Operations for Plant Personnel
Charlotte, North Carolina
Contact: Richard Pennington, 704-547-6105

26–28
Forward Curve Individual Dynamics
Austin, Texas
Contact: Peggy Prater, 650-855-2951

27
Water and Energy Conference
Dallas, Texas
Contact: Kim Shilling, 314-935-8590

28–29
Municipal Water and Wastewater Program Meeting
Dallas, Texas
Contact: Kim Shilling, 314-935-8590

October

2–3
Containment Inspection: Visual Examination Training, Level 2
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

3–5
Valve Packing Configuration, Implementation, and Program Development
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

4–6
Distributed Resources Conference 2000: Opportunities, Applications, Technologies, and Regulatory Policy
Tucson, Arizona
Contact: Laura Goldie, 650-855-2560

8–11
Gasification Technologies Conference
San Francisco, California
Contact: Neville Holt, 650-855-2503

10–12
ASME Section XI Flaw Evaluation
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

10–12
Neural Networks and Fuzzy Logic Control With Engineering Applications
Kingston, Tennessee
Contact: Sherryl Stogner, 704-547-6174

16–20
Visual Examination: Level 1
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

17–18
Power Quality Interest Group
Knoxville, Tennessee
Contact: Marsha Grossman, 650-855-2899

17–19
NO_x Controls for Utility Boilers
Arlington, Virginia
Contact: Barbara McCarthy, 650-855-2127

18–19
TFLASH 6.0 Training Seminar and Users Group Meeting
Lenox, Massachusetts
Contact: Kyle King, 413-448-2459

23–26
Tropospheric Aerosols: Science and Decisions in an International Community
Querétaro, Mexico
Contact: Alan Hansen, 650-855-2738

23–27
Simulator Instructor Techniques
Charlotte, North Carolina
Contact: Richard Pennington, 704-547-6105

23–November 3
Ultrasonic Examination: Level 2
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

24–27
Energy Book Workshop and Interest Group Meeting
Washington, D.C.
Contact: Peggy Prater, 650-855-2951

24–27
Short Course on Closed Feedwater Heaters
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

31–November 1
Power Quality Interest Group
Knoxville, Tennessee
Contact: Josephine Garcia, 650-855-2833

November

1–2
Adjustable-Speed-Drive Applications and Lab
Knoxville, Tennessee
Contact: Lynn Stone, 972-556-6529

1–3
Forward Curve Introductory Training
Maui, Hawaii
Contact: Peggy Prater, 650-855-2951

4–5
NMAC Shaft Alignment Workshop
Charlotte, North Carolina
Contact: Linda Parrish, 704-547-6061

6–7
Simulator Specification and Procurement Workshop
Charlotte, North Carolina
Contact: Richard Pennington, 704-547-6105

6–10
Advanced Power Line Structure Analysis and Design Methods
Haslet, Texas
Contact: Gayle Robertson, 817-439-5900

6–10
NDE for Engineers
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

7–10
Simulator Acceptance Testing Procedures Workshop
Charlotte, North Carolina
Contact: Richard Pennington, 704-547-6105

13–15
Balance-of-Plant Heat Exchanger NDE and Condition Assessment for Engineers
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

13–17
Visual Examination: Level 2
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

27–December 1
Ultrasonic Examination: Level 3
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174